STATE OF CALIFORNIA

DEPARTMENT OF PUBLIC WORKS

DIVISION OF ENGINEERING AND IRRIGATION

BULLETIN No. 4

WATER RESOURCES OF CALIFORNIA

A REPORT TO THE LEGISLATURE OF 1923

CALIFORNIA STATE PRINTING OFFICE
FRANK J. SMITH, Superintendent
SACRAMENTO, 1923

25712

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LETTER OF TRANSMITTAL.

January 1, 1923.

To the Members of the Legislature,
State of California,
Session of 1923.

The report on the "Water Resources of California," prepared by the Division of Engineering and Irrigation of this Department, is transmitted herewith. This report compiles the results of the state-wide investigation authorized by Chapter 889 of the Statutes of 1921. In placing this in your hands, I desire to mention the helpful services of the Consulting Board appointed pursuant to the provisions of the act and of the members of the civil engineering profession who have served on advisory committees and reviewed much of the work in preparing this report. They have freely given to the state valuable advice and assistance that have greatly aided these endeavors.

Respectfully submitted.

ABFletcher

Director of Public Works.

LETTER FROM THE CONSULTING BOARD TO THE MEMBERS OF THE LEGISLATURE.

To the Honorable Members of the Legislature,
State of California,
Session of 1923.

The Consulting Board appointed under the provisions of chapter 889 of the Statutes of 1921, approves the report of the Division of Engineering and Irrigation of the State Department of Public Works, herewith submitted.

It is the judgment of the Board that the Division of Engineering and Irrigation should continue this work and that the required appropriation therefor should be made.

Respectfully submitted.

J. C. Forkner, *Chairman*
Peter Cook
Nathan C. Dodge
B. A. Etcheverry
Harry Haywood
H. A. Kluegel
R. W. Marshall
W. D. McGlashan
Otis B. Dow
A. D. West

Members of Consulting Board.

ACKNOWLEDGMENT.

Much data have been contributed to this report by public and private offices without which the Department would have been wholly unable to produce this volume. The Department desires to publicly express its sincere appreciation to the parties who, through the furnishing of these data, have made it possible to increase the service to the public several-fold, in publishing this report.

FOREWORD.

The legislature of 1921 appropriated $200,000 for an investigation of California's water resources by the State Department of Public Works, Division of Engineering and Irrigation. Accordingly, an engineering investigation has been completed and a report transmitted to the legislature on January 1, 1923. The great mass of data collected and the complex analyses thereof made it advisable to present much of the information in separate volumes. Four of these are in print, entitled:

Appendix "A"	"Flow in California Streams." Bulletin No. 5, State Department of Public Works.
Appendix "B"	"Irrigation Requirements of California Lands." Bulletin No. 6, State Department of Public Works.
Appendix "C"	"Utilization of the Water Resources of California." Bulletin No. 7, State Department of Public Works.
Appendix "D"	"Relation of Settlement to Irrigation Development." Bulletin No. 8, State Department of Public Works.

Chapter 889 of the 1921 Statutes, which authorized this investigation, provided for the appointment by the Governor, of a Consulting Board to advise with the Department in their endeavors. The following were appointed by Governor Stephens:

J. C. Forkner, Chairman
Peter Cook
Jonathan S. Dodge
B. A. Etcheverry
Harry Hawgood
H. A. Kluegel
Robert B. Marshall
H. D. McGlashan
O. B. Tout
U. S. Webb

Additional advice on the technical features of Appendix "A" to this report has been sought by the Department from:

C. E. Grunsky
Louis C. Hill
Charles D. Marx
H. D. McGlashan

Also, further advice was sought on the technical features of Appendix "B" from:

A. N. Burch
B. A. Etcheverry
Samuel Fortier
A. L. Sonderegger

The Department sought added advice on the technical features of Appendix "C" from:

A. J. Cleary
G. A. Elliott
F. C. Herrmann
W. L. Huber
A. Kempkey
William Mulholland

Appendix "D" was prepared by Dr. Elwood Mead, Professor of Rural Institutions of the University of California, and Chief of Division of Land Settlement of the State Department of Public Works, under cooperative arrangements with the University of California.

ORGANIZATION.

A. B. FLETCHER, *Director of Public Works*
W. F. McCLURE, *Chief of Division of Engineering and Irrigation*

The investigation of the water resources of the state and the preparation of the report thereon, was planned, directed and brought to completion by

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T. NEUMAN
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L. O. Newsome
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Earl D. Stafford
J. E. Stafford
G. H. Walters
A. V. Wilson

A. F. McConnell, Editor of Report
J. J. Haley, Jr., Office Manager

CHAPTER 889 OF STATUTES OF 1921.

An act to provide for the investigation by the State of California of the possibilities of the storage, control and diversion of water for public use and public protection in the State of California, and making an appropriation for said purpose.

(Approved June 3, 1921.)

The people of the State of California do enact as follows:

SECTION 1. It is hereby declared that the people of the State of California have a paramount interest in the use of all the waters of the State and the State of California shall determine what waters of the state, surface and underground, can be converted to public use, or controlled for public protection.

SEC. 2. The state engineering department is hereby authorized and instructed to make the investigation in this act provided for and for the purposes herein specified.

SEC. 3. It shall be the duty of the state engineering department to determine the maximum amount of water which can be delivered to the maximum area of land, the maximum control of flood waters, the maximum storage of waters, the effects of deforestation and all possibile and practicable uses for such waters in the State of California.

SEC. 4. It shall be the duty of the state engineering department to determine a comprehensive plan for the accomplishment of the maximum conservation, control, storage, distribution and application of all the waters of the state, and to estimate the cost of constructing dams, canals, reservoirs or other works necessary in carrying out this plan, and to report the result of such investigations with recommendations not later than the legislative session of 1923.

SEC. 5. In carrying out the provisions of this act the state engineering department is hereby authorized to examine any and all data, estimates and proposals in furtherance of the above purpose, according to its judgment of their engineering worth, and to cooperate with any department, bureau, office, service, or division of the United States, or of the state or counties, or with any municipality, irrigation, reclamation, conservation, drainage, flood control, levee, or other district agency for irrigation, reclamation, drainage, or flood control purposes, or for the development of hydro-electric power; or with any interested association, company or individual; *provided, further,* that the engineering department is hereby expressly authorized to accept, receive and use any funds or moneys contributed to it by any person, irrigation district, reclamation district, water and conservation district or any political subdivision of the State of California for the purpose of cooperating in the work aforesaid and carrying out the purposes of this act.

SEC. 6. With the approval of the governor, the state engineering department is hereby authorized to employ such assistance as in its judgment it may require and to incur such expense as may be necessary to carry out the purposes of this act. The governor is further authorized to appoint a consulting board, composed of citizens of special and technical qualifications, to serve in an advisory capacity, and without pay, in making the above investigation.

SEC. 7. There is hereby appropriated out of any money in the state treasury, not otherwise appropriated, the sum of two hundred thousand dollars, and made immediately available for any of the purposes of this act.

SEC. 8. This act shall not in any way be construed so as to deprive persons, corporations, or districts of vested rights.

SEC. 9. Any section or portion of a section of any act, statute or law of the State of California in conflict with the provisions of this act is hereby repealed.

LIST OF TABLES.

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CHAPTER I.

RECOMMENDATIONS TO THE LEGISLATURE OF 1923.

One-third of the aggregate value of all of California's products are those raised on the farm, and one-fourth of all its manufactories are concerned in milling, canning or preserving, cleaning, or otherwise preparing food stuffs for the market. In a state whose wealth is taken from the soil in such large portions, agriculture and the problems attendant to its expansion, press for consideration. The accelerated expansion of agricultural production in California has been attained through the more intensive cultivation of its fertile soils. Irrigating about one-third of all the lands farmed, this state now yields an average crop value that is almost three times larger for each acre cultivated,[1] than the average production on an acre of tilled land in any of the three states that exceed California in total annual production on their farmed lands. The abundant soil-moisture obtained through the supplementary supplies, has enabled the responsive soils of California to produce many fold under irrigation and is placing this state in a foremost position among the states of a nation of farms.

Even more than in the past, will the future be concerned in the extension of irrigation to additional areas and the perfection of the supply for those lands now watered, because the agricultural lands of this state are now yielding to capacity under the conditions of dry farming. It is therefore essential that state activities should be guided by thoughts for the orderly and economical development of its water resources, so that all the needs of civilization for water may be supplied while the predominant use for agriculture may expand to the full limit of its wealth-producing powers. In this report, the Department of Public Works and its consultants have endeavored to compile and present information on the water resources of California that will enable your honorable body to guide the state's destiny with confidence and wisdom.

The data amassed, the comparisons, the computations and the deductions involved in preparing this report, are so voluminous that they are printed in four separate volumes. Appendix "A," "Flow in California Streams," in seventy-six pages of text, two hundred and forty-four pages of tables, and in one hundred and eighty-five maps and diagrams, describes the location, the volume, the source, and the variability of occurrence of the state's waters, and the capacities of storage works required for their utilization. Appendix "B," "Irrigation Requirements of California Lands," in seventy-six pages of text, one hundred and fifteen pages of tables and seven maps and diagrams, gives a digest of all information obtainable on the past use of water for irrigation, and presents an analysis of the future requirements of all

[1]The California State Department of Agriculture estimates the average value of farm products per acre for the four ranking states in 1922, was, in order of their total production: Texas, $27.50; Iowa, $21; Illinois, $20; and California, $59.50.

of California's arable lands. Appendix "C," "Utilization of the Water Resources of California," presents a general preliminary plan for obtaining the maximum use from the state's waters and the control of floods. Appendix "D," "Relation of Settlement to Irrigation Development," discusses colonization problems of irrigation projects. All this information, basic for a full conception of the potential value of the state's water resources, its greatest possession, is briefly summarized in the chapters of this report.

A general preliminary plan for achieving the greatest service from these waters, is presented as requested by the legislative enactment providing for these investigations. This plan outlines a scheme of coordinated development whereby a maximum accomplishment may ultimately be obtained whose physical works for storing water would cost but slightly more than half as much as similar attainment under an uncoordinated plan. The canals for transporting this water to the regions of use are, many of them, very long and obtain water from several sources, pass through numerous communities, and could be made possible only through organization of large sections of the state. Without such canals much of the state's waters will go unused. Only then, through united endeavors, almost statewide in extent, can the maximum service be obtained from the state's waters.

The reservoirs involved in the maximum development of the state's waters are some 260 in number. These and twice as many more were examined by field parties in these investigations, and a selection made of a third of all the possible sites reported on. Time did not allow, neither did the preliminary investigation warrant, a detailed examination of dam sites. Before it is finally known that the selected sites are feasible, borings and exploration trenches must be made. The canals outlined on the map of the comprehensive plan, largely pass through territory of which adequate maps do not exist. Many surveys must be made before it may be ascertained that these canals are feasible and that they are in the most economical location. *It is therefore recommended to your honorable body that funds be appropriated to pursue the study of the comprehensive plan in greater detail than has been possible for this report.*

It is also desired to call to your attention the value of records of the waters flowing in California streams. Because of the sporadic way in which the waters pass down the stream channels, reliable estimates of future expectancies can only be made from uninterrupted records of many years' duration. The inventory of the state's waters presented in this report has been based on an estimated fifty-year mean flow. This was accomplished by expanding records of measured run-off through comparison with precipitation records and, on many streams, the entire estimate of run-off was obtained by comparison. It is urgent that provision be made for the continuance of stream gaging records at least as extensive as in the past, and some increase be made in appropriations for this work if possible. The construction of all the great hydraulic works on which the future wealth of this state depends, must be designed in accord with these records of stream flow. It is important that they be continuous and on all the streams.

Lastly, the desirability of stimulating the rate of rural settlement in California has been pointed out in this report. This subject is placed before you as one worthy of your attention.

CHAPTER II.

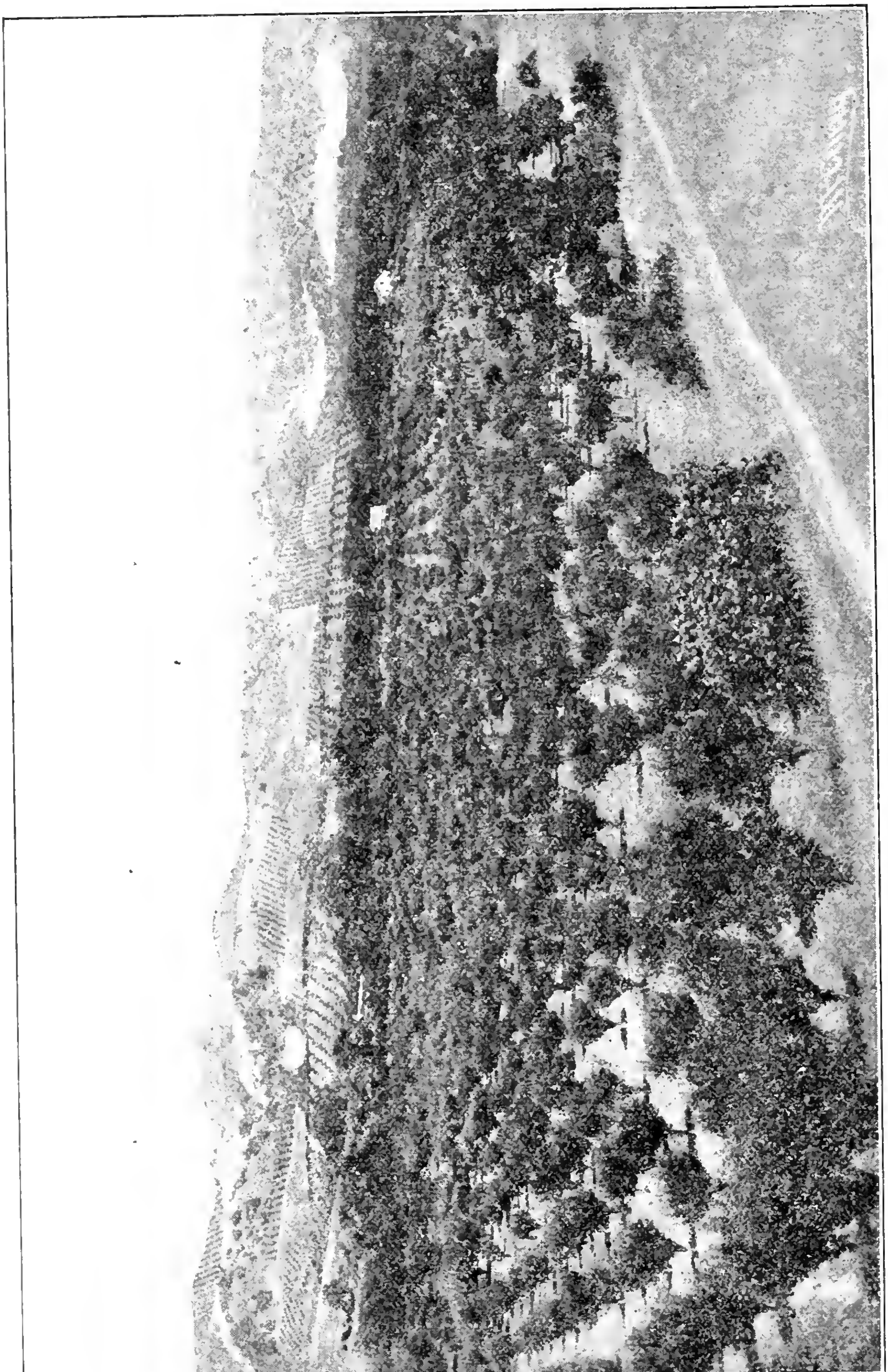
CALIFORNIA.

California, second in area, but first among the states of the Union in value of natural resources, lies between the Great Basin of the North American continent and the Pacific Ocean. Confined on the north by Oregon and on the south by Mexico, it constitutes three-fifths of the western boundary of the United States. The six hundred and fifty miles of its meridional length extends to over nine hundred miles of seashore as the coast line pursues a diagonal and more tortuous course in delineating the headlands and coastal indentations of the Pacific littoral.

Within the two hundred miles of California's average width, there are 23,000,000 acres of agricultural lands disposed in parcels of various sizes and separated by mountains that occupy much of the intervening space. These agricultural areas are the flat and rolling lands of the state that have soils, disposed in appreciable areas of regular surface conformation, suitable for the production of harvestable crops. The grains, fruits, berries, grapes, vegetables and other farm produce for which California is famed, are grown on these lands. They are located on the valley floors, in the foothills and on the plateaus of the state. Included in the agricultural areas, are lands at present deficient in natural moisture, but more or less conveniently situated for the ultimate acquisition of an accessory water supply. Slightly over one-half of these agricultural areas were farmed in 1920.

The non-agricultural regions of California, the mountains, are, for the most part, precipitous, rocky or soilless. Occupying three-fifths the area of the state, these upland regions are spacious collectors of precipitation that fill the stream channels with water, without which much of the state's arable lands could never reveal their powers of production because of deficient soil-moisture. Although they are mostly non-tillable, nevertheless the mountainous regions have supplied the alluvial earth through glacial action, weathering or erosion, that their streams have conveyed to lower levels and deposited there to become the fertile, productive soils of the agricultural areas.

California's mountains are so disposed that their greater part is comprised within two ranges. These diverge in their southerly course at Mount Shasta within forty miles of the Oregon line, and leave between their bases, the long flat valley that averages a quarter the breadth of the state and half its length. Girdling this valley in their southward course, these two mountain chains proceed in long sweeping curves to a convergence at Tehachapi Pass, three-quarters the way down the state from the north boundary. The encircling line of crests of these two ranges enclose within a rock wall, two-thirds of California's agricultural lands. This wall is cleft to valley-floor level in but one



AGRICULTURAL LANDS IN FOOTHILL REGION.

place. Through this cutting, the interior drainage issues, flowing westwardly to mingle with the waters of the Pacific Ocean.

The mountains to the east of this Great Central Valley, the Sierra Nevada Range, extend for two-thirds the length of the state between Mount Shasta on the north and Tehachapi Pass on the south and their crests are the highest of California's mountains. Serrated and precipitous, their altitudes increase from north to south and culminate in Mount Whitney, 14,500 feet high, the highest peak in the United States excluding Alaska. Between the two extremities of this range, many peaks rise to heights greater than 8000 feet above the sea and eleven peaks pierce the clouds to more than 14,000 feet. In the northerly quarter of this range is Lassen, the culminating peak of its vicinity, 10,580 feet high and North America's only active volcano.

The westerly of the two mountain chains encircling the Great Central Valley, the Coast Range, after separating at Mount Shasta from the mass of mountains in the northern part of the state, parallels the margin of the Pacific Ocean and takes a somewhat narrower path in its southerly course, than does the Sierra Nevada Range. The Coast Mountains do not attain the elevations of the Sierra Nevadas, neither are they so diverse of surface or massive in structure. Their highest peaks are less than 9000 feet in elevation and those above 5000 feet are but few in number.

Southward from the convergence of these two ranges at Tehachapi Pass and on to the Mexican Border, California's mountains continue as a single chain. Their crests are less continuous and their main axis is less easily discernible than from the Pass northward. A few dominating peaks rise to heights of more than 10,000 feet, but their general altitude is intermediate in elevation between those of the Coast Range and Sierra Nevada Mountains.

This mountain range divides two very diverse regions. To the west, the Pacific slope, the agricultural lands of which extend from the ocean's margin well up to the mountain flanks, is an intensively developed and highly productive area of moderate climate fluctuation; while to the east lies an undeveloped expanse, almost rainless, with climatic extremes, and largely unproductive through lack of an accessory water supply. However, there are extensive productive areas in Imperial, Palo Verde and Coachella valleys which have acquired irrigation supplies and are realizing on the great fertility of their arid soils. In this expanse of flat lands and mountains is Salton Sink, an inland sea, the surface of which is more than 250 feet below ocean level.

On the Pacific slope of this dividing range in the southern quarter of the state, in its broad valleys and adjacent to the seashore, is spread the bulk of California's agricultural lands that lie west of the state's mountains, in all, one-sixth of their total area. These lands are located mostly along the streams near their ocean outlets. Northward from Santa Barbara Channel they are scattered rather meagerly along the Pacific margin, for their continuity is interrupted by extensive stretches of precipitous shore line that rises abruptly from the water's edge.

To the east of Southern California's dividing range south of the Tehachapi Pass, one-tenth of the state's arable lands lie between their crests and the state's eastern border. Northerly from these lands and along the eastern border of the state, another tenth of the agricultural

DOMINATING HEIGHTS OF THE SIERRA NEVADA MOUNTAINS.

lands are located in scattered parcels in the elevated valleys and plateaus east of the crests of California's mountains. These are mostly situated at elevations of from 4000 to 5000 feet or more above sea level.

The extreme range in altitude of California's variegated surface is from two hundred and seventy-five feet below sea level in Death Valley, to fourteen thousand five hundred feet above, attaining this elevation at Mount Whitney, but seventy-five miles distant from the lowest depression. The greater part of the flat lands, or about one-fifth of the total area of the state, lies between the elevation of the ocean's edge and five hundred feet above. These flat lands comprise the gently sloping ocean littoral, an extensive mountain-girdled valley known as the Sacramento-San Joaquin, and the almost rainless area in the southeastern corner of the state. These regions, 33,000 square miles in extent, include the bulk of California's agricultural area.

Higher in elevation than these flat lands, are the slopes lying between the plain-like areas and the base of the mountains. These are the rolling foothills and the more elevated valleys, lands that are transitional between the plains and the highland regions. Located between 500 and 2500 feet above sea level, they comprise about one-third the area of the state. One-quarter of all the agricultural land lies in this transitional region, and only the scattered parcels in high mountain valleys and that on the plateau in northeastern California, lie above it.

Higher than 2500 feet in elevation lie the mountains proper. For a large part they are a rugged and precipitous region of steep acclivities, of rocky extrusions and serrated ridges, and of deep canyons and rock-walled gorges, that comprise nearly half the area of the state, but interspersed at intervals throughout this highland region are mountain valleys and meadows, attractive in their richness and scenic beauty. The mountain and foothill regions, together, are over triple the area of the agricultural lands. In receiving greater precipitation, the mountain regions shed large volumes of water into the streams and rivers and are the source of nearly all of the state's waters.

CHAPTER III.

CLIMATE.

The California year is distinctive from that in most other states of the Union, in having but two well-defined seasons, summer and winter. This occurs because the transitional periods, spring and autumn, are brief and devoid of special features other than that they are intermediate between the more clearly defined seasons of summer and winter. The summer, or growing period, is long, warm and without heavy rains; the winter is the dormant period, or interval of retarded growth in the annual cycle of plant life, and normally is short, cool, and at times stormy. The greater portion of the waters precipitated upon the lands of California fall during this season of winter.

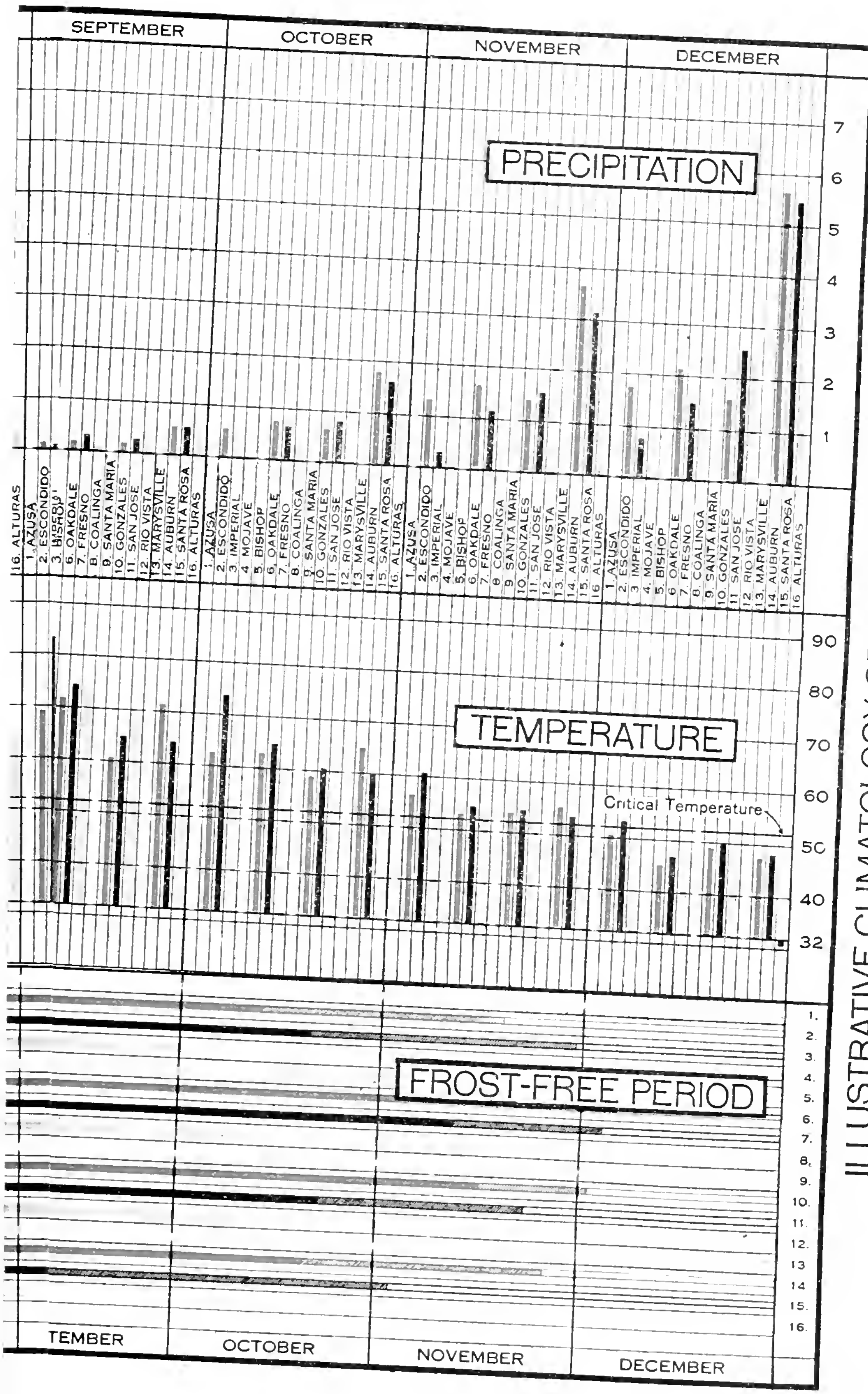
The covert of encircling mountains and the proximity of an ocean that borders the state with nine hundred miles of coast line, so modifies California's climate that only moderate seasonal fluctuations of temperature occur over most of its area. Any great extremes of heat and cold that do transpire are confined principally to the high mountain or arid areas. On the low lands generally, the mean monthly temperatures show departures from the average for the entire year, markedly less than similarly compared heat measurements for the adjoining states or those located eastward and included in the same latitude.

California is exempt from hurricanes and tornadoes, and though the mountainous regions experience days of intense cold, blizzards are unknown over the valley areas. Favored of nature through immunity from devastating tempest, rigorous cold, and enervating heat, California's climate is heralded the world over.

The outstanding features of the state's climatic regime are the rains of winter and the sunshine of summer. During the winter months, the state is swept by moisture-laden winds that traverse large areas in their journey from one locality to another; while in the summer or dry season, similar winds may blow, but they are rainless and serve only to modify the mounting temperatures that ensue from continuous sunshine. This distinct division of the year into a short season of intermittent drenching rains and a longer season of warmth and sunshine, determines that, more and more, in the years to come, this peculiarity of climate will influence the activities of man in this state. As greater numbers of people elect to live within its borders, water will be needed in increasing amounts for every activity, and all of California's waters originate in the precipitation concentrated in a few months of the year.

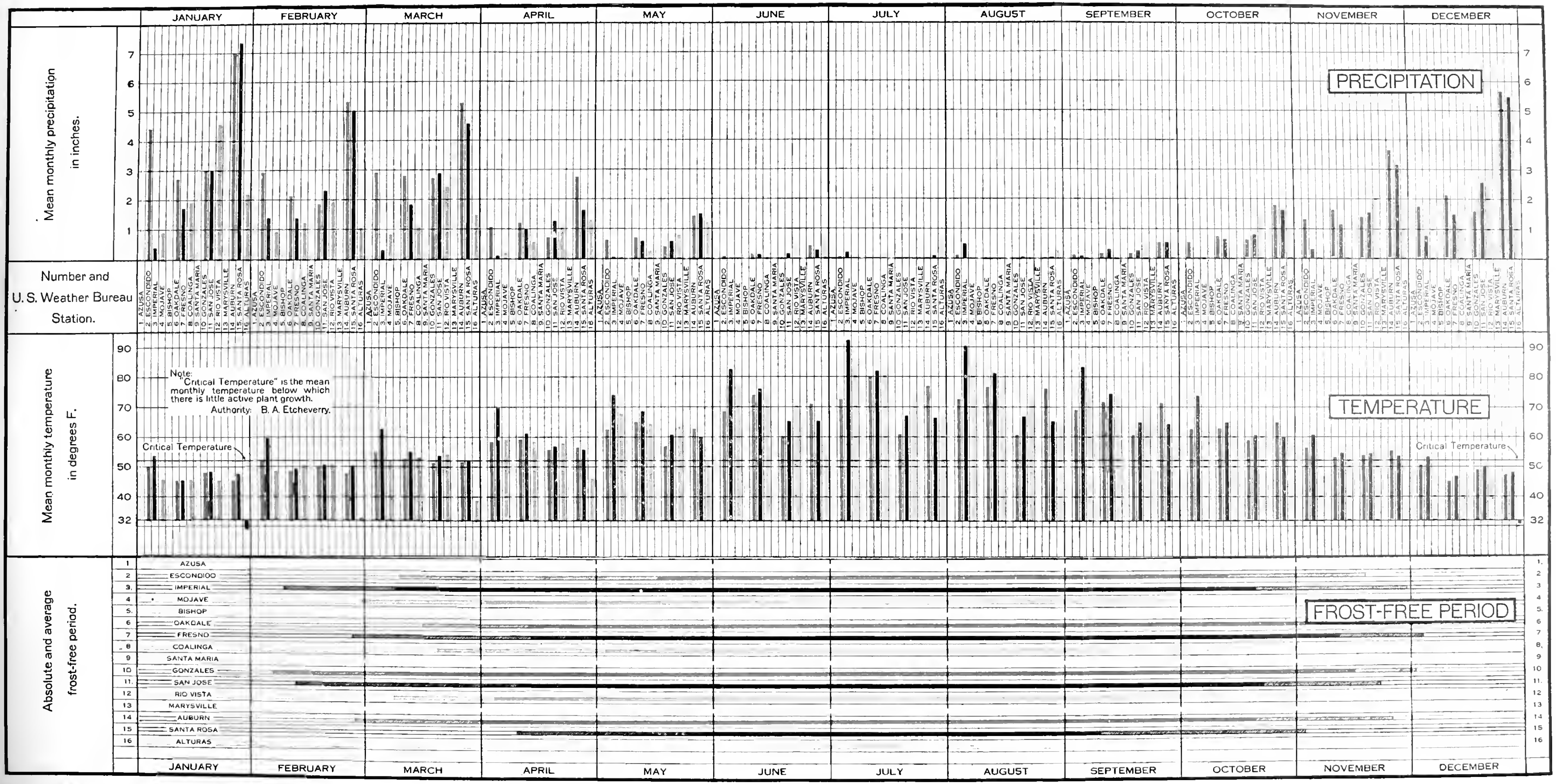
Of greatest economic importance therefore, among the climatic phenomena, are the moisture-carrying winds that visit the state at annually recurrent intervals. In blowing over the land areas, these winds precipitate varying amounts of water along the way as they are cooled, and deflected or diverted by local topography. The shelter of knolls, of hills or mountains, or of ridges or spurs, may lessen the amounts reaching leeward areas, while increased quantities may fall on more

Plate I



ILLUSTRATIVE CLIMATOLOGY OF AGRICULTURAL LANDS

STATE DEPARTMENT OF PUBLIC WORKS
DIVISION OF ENGINEERING AND IRRIGATION
CALIFORNIA WATER RESOURCES INVESTIGATION
CHAPTER 889 1921 STATUTES



ILLUSTRATIVE CLIMATOLOGY OF AGRICULTURAL LANDS

STATE DEPARTMENT OF PUBLIC WORKS
DIVISION OF ENGINEERING AND IRRIGATION
CALIFORNIA WATER RESOURCES INVESTIGATION

exposed locations. The greater cooling of the air upon moving up slopes and arriving at higher elevations, usually inceases the precipitation in the mountainous regions over that on lower lands.

The annual quantity of moisture released from the atmosphere to fall upon the several parts of the state, is as variant as the rugged topography.[1] In general, precipitation increases in depth from south to north, being least in the southeastern corner of California where it is nearly zero, and greatest in the North Pacific region contiguous to the Oregon line where the mean annual rainfall attains a depth of one hundred inches or more. The mountains generally receive more than the valleys between them. The greater portion of the flat lands have a mean depth of precipitation of less than twenty inches annually and one-third of their area has less than ten inches. Depths of more than twenty inches are mostly confined to the mountainous regions which on their more elevated portions receive from thirty-five to one hundred inches, or more. In the highest mountain regions, precipitation occurs largely as snow; on those of lesser altitude both snow and rain fall, but the mantle of snow on the earth is of short duration; while the areas lying closer to the ocean's level, seldom experience a fall of snow but receive all precipitation as rain. The mild climate of this lower portion of the state extends, therefore, to nearly all its flat-lands, to the gently sloping ocean littoral, to the extensive mountain-girdled valley containing three-fifths of all the agricultural lands, and to the rolling foothills and detrital-filled valleys transitional to the highland regions—in all about one-half the area of the state.

To depict the features of rain, temperature and frost in California's agricultural areas, Plate I has been prepared, "Illustrative Climatology on Agricultural Lands." For convenience, the tillable lands of the state have been segregated into sixteen divisions or sections, the boundaries of which are shown on Plate III, "Map of Agricultural Areas and Duty of Water Sections." A station of the United States Weather Bureau has been selected in each one of these sections to illustrate its climatic features, and the mean precipitation and temperature for each month of the year, together with the frost-free periods for each one of these stations is graphically delineated on Plate I.

The top section of this plate shows, by means of colored columns drawn upwardly from a common base line, the mean monthly precipitation that has occurred at the Weather Bureau Station that is named at the foot of the bar. At the extremity of each equally-spaced cross-line on the sheet, at the left margin, are numerals which express values of mean monthly precipitation in inches of depth. The colored columns in intercepting these cross-drawn lines, indicate by their height, the amount of mean monthly precipitation.

On the middle section of the Plate I, the mean temperatures that have prevailed during each month of the year at the stations named above them, are represented by similarly colored columns that also project upward from a common base line. These show the values of mean monthly temperatures by their intercepts on cross-drawn lines that are numbered with temperature values at the left margin.

[1]See Isohyetose Map of California contained in Appendix "B" to this report, for complete delineation of precipitation over the state.

exposed locations. The greater cooling of the air upon moving up slopes and arriving at higher elevations, usually inceases the precipitation in the mountainous regions over that on lower lands.

The annual quantity of moisture released from the atmosphere to fall upon the several parts of the state, is as variant as the rugged topography.[1] In general, precipitation increases in depth from south to north, being least in the southeastern corner of California where it is nearly zero, and greatest in the North Pacific region contiguous to the Oregon line where the mean annual rainfall attains a depth of one hundred inches or more. The mountains generally receive more than the valleys between them. The greater portion of the flat lands have a mean depth of precipitation of less than twenty inches annually and one-third of their area has less than ten inches. Depths of more than twenty inches are mostly confined to the mountainous regions which on their more elevated portions receive from thirty-five to one hundred inches, or more. In the highest mountain regions, precipitation occurs largely as snow; on those of lesser altitude both snow and rain fall, but the mantle of snow on the earth is of short duration; while the areas lying closer to the ocean's level, seldom experience a fall of snow but receive all precipitation as rain. The mild climate of this lower portion of the state extends, therefore, to nearly all its flat-lands, to the gently sloping ocean littoral, to the extensive mountain-girdled valley containing three-fifths of all the agricultural lands, and to the rolling foothills and detrital-filled valleys transitional to the highland regions—in all about one-half the area of the state.

To depict the features of rain, temperature and frost in California's agricultural areas, Plate I has been prepared, "Illustrative Climatology on Agricultural Lands." For convenience, the tillable lands of the state have been segregated into sixteen divisions or sections, the boundaries of which are shown on Plate III, "Map of Agricultural Areas and Duty of Water Sections." A station of the United States Weather Bureau has been selected in each one of these sections to illustrate its climatic features, and the mean precipitation and temperature for each month of the year, together with the frost-free periods for each one of these stations is graphically delineated on Plate I.

The top section of this plate shows, by means of colored columns drawn upwardly from a common base line, the mean monthly precipitation that has occurred at the Weather Bureau Station that is named at the foot of the bar. At the extremity of each equally-spaced cross-line on the sheet, at the left margin, are numerals which express values of mean monthly precipitation in inches of depth. The colored columns in intercepting these cross-drawn lines, indicate by their height, the amount of mean monthly precipitation.

On the middle section of the Plate I, the mean temperatures that have prevailed during each month of the year at the stations named above them, are represented by similarly colored columns that also project upward from a common base line. These show the values of mean monthly temperatures by their intercepts on cross-drawn lines that are numbered with temperature values at the left margin.

[1]See Isohyetose Map of California contained in Appendix "B" to this report, for complete delineation of precipitation over the state.

The lower section of the plate, designated "Frost Free Period," has transverse bars which progress partially across the paper. In so doing, their length exemplifies time. The space between the left and right hand margins represents the full twelve months of the year. Vertical lines divide this space into equal units of time and the monthly intervals are accentuated by heavier drawn lines. Spreading across the sheet and crossing these vertical lines, the sections of the bars in solid color show the duration of the period at each of the sixteen Weather Bureau stations, within which frost has never occurred. Extensions of the bars, hatched with colored shading lines, show by the distance between their extreme ends, the average duration of the frost-free period for the years of record. The bars are similarly colored to the columns of temperature and precipitation and are named at the left margin opposite their ends.

Plate I illustrates in a pictorial way, the climatic characteristics that prevail over California's agricultural lands. The precipitation section of this graph shows that almost without exception, the rainfall in amounts to be of much value to agriculture, is confined to the months of November, December, January, February and March; while the temperature section shows that the period favorable to the growth of plants and vegetation, is from March to November, inclusive. Except for March and November, the rains in California occur during the time of the year in which most plants are dormant and for seven warm months of the long growing season, the rains on the agricultural lands are light. Thus for a period during each twelve months, California is favored with precipitation-releasing winds, and once a year at coinciding times, the mountain ranges are clothed in snow, foothill eminences and slopes are drenched with rain, and valleys and plains are wetted by the same spacious storms; while through the remainder of the annual cycle, sunshine and warmth are dominant and precipitation is small in amount.

CHAPTER IV.

THE STATE'S WATERS.

The moisture-bearing winds that traverse California during the winter season precipitate three hundred billion tons of water annually upon the surface of the state. Most of this falls as rain or snow upon the mountain areas. This precipitation: as rain, strikes the surface of their slopes, off which portions run toward lower elevations; as snow, it mantles the earth's surface or collects in wind-blown drifts to await warmer temperature for conversion to liquid water, that may likewise pursue a downhill course toward the ocean.

These moving waters, ever journeying to lower elevations, concentrate in the ravines and gullies toward which the surfaces slope. They follow the steepest gradients and the most deeply cut depressions and, continually enhanced in volume by like accumulations, restlessly pursue their downward course until finally they become engulfed in the earth's vast reservoir of waters—the ocean. Falling on the drainage areas as precipitation, concentrating on the land surface as run-off, coursing down the water-channels as stream flow, these waters reach the ocean as drainage; and so by returning to the storehouse of waters from which they were first vaporized and carried to the mountainous area by the moisture-bearing winds, they complete a circuit of travel.

The same storms that drench the uplands or clothe them in snow, precipitate lesser amounts on the lower flat lands, and this almost entirely as rain. Lacking the surface inclination to put the water in motion, the earth coverings of these lowland areas largely absorb the rains falling upon them or, detained in pools or puddles or in the saturated top soil, they are later evaporated back to the atmosphere. Only during extremely heavy downpours of infrequent occurrence do the flat lands contribute run-off to the stream channels.

California's water-producing area is the mountains. Influenced by the topography, elevation, and exposure of the divers localities, the storms traversing the state deposit varying quantities of water on their diverse surfaces. In each area, however, only a portion of the waters cast from the clouds ever reach the stream channels; the rest is dissipated through evaporation. This division of the waters starts immediately with their precipitation from the rain clouds and continues throughout the entire water movement. Moisture is evaporated from the falling particles of rain or snow, from the gathering waters on their catchment areas, from the snow fields, from wetted soil areas, and from the flowing streams. Water is also vaporized from the vegetation that grows on the mountain slopes. Much of the moisture that wets the earth's surface is absorbed by the root systems of vegetation, so that where trees, bushes and undergrowth are dense, large volumes of water are vaporized through transpiration from plant-surfaces. So evaporation is persistently in progress, and, effectively and without respite, reduces the volumes of water precipitated upon the earth's sur-

A STREAM IN THE SIERRA NEVADA MOUNTAINS.

face. The fraction of these waters finally becoming stream flow in each season may be less than one-fourth or more than three-fourths of the total precipitation, according to the amounts falling, the contingencies of the season's weather, and the circumstances of topography and geology on the catchment areas.

Except as it falls upon frozen or nonabsorbent surfaces, precipitation upon striking the earth must first moisten its top-covering, and it is only after this has become saturated that waters gather on the surface to journey down the slopes of the catchment areas. While collecting in puddles and pools or moving down the slopes in streamlets, some of this run-off trickles into seams and cracks of the mountain's rocky structure, while other quantities are absorbed by pervious soil-coverings. This moisture advances by the attractions of gravity and capillarity and, filling the pores and interstices of the earth's crust, penetrates to great depths. Although usually only a small portion of the total, these percolating waters are especially valuable to man in their reappearance at lower elevations as perennial springs to moisten meadow lands or to increase the waning summer flow of brooks and streams. These tardy waters, in penetrating the subsurface regions and pursuing a dilatory underground course, wet the beds of the stream channels the year round and furnish nearly all of the dry season stream flow, and are the principal waters available when the great volume of winter run-off has subsided. Their total amount, however, is small, for three-fourths of the run-off from California's mountains concentrates in the stream channels, hurries down the water courses and passes by the low-lying agricultural lands within forty-five days after its precipitation upon the earth's surface.

Following precipitation so closely, the state's waters appear in the stream channels in fluctuating flows having a striking similarity to the periodic occurrence of precipitation. Plate II, "Characteristics of Run-off from California Mountains," presents the hydrographs of five streams, each typical of a separate section of the state. These hydrographs show the run-off, month by month, for the greatest year and for the least, as well as the mean monthly flow of all the years of record. For convenience of comparison, the monthly run-off is plotted in per cent of the annual mean. These hydrographs show how the bulk of California's waters run off their mountain catchment areas during the winter months, and how only meager quantities flow in the streams during the middle and late summer. The great variation between the run-off of the maximum and minimum years shows the wide limits between which seasonal run-off fluctuates, and how, in the smallest season, the usual scanty summer flow is much reduced and this much earlier in the season than in other years.

This investigation has studied the features of flow in all the streams of the state,[1] the amounts of their waters, and their variability of production. All discoverable data have been assembled and analyzed and, although actual measurements of flow are available but for a limited number of years on the major streams, through comparison of these data, quantities have been ascertained for every stream. For these purposes the minor streams were arranged in groups and these groups, together with the major streams, total one hundred and forty in number. The location of each one of these streams or groups of

[1]See Appendix "A," "Flow in California Streams."

minor streams is shown on the map of California, Plate IV, "Preliminary Comprehensive Plan for Maximum Development of California's Water Resources." Each basin bears a number on this map which refers to a table at the top of the sheet. This table gives the name of the stream draining the basin or the main stream in the group of small basins.

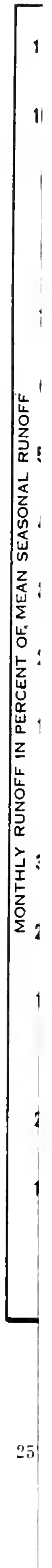
An audit of all these waters is presented in Table I, "Water Resources of California," in which is a complete inventory of the state's waters. In listing the flow at the head of the main body of agricultural land on each stream, the waters in this table are practically all that are available, both surface and underground, for use on the flat lands of the state for the subterranean waters of the flat lands largely receive their supply by percolation from the stream channels crossing them or from percolation of diverted waters poured out upon their land surfaces.

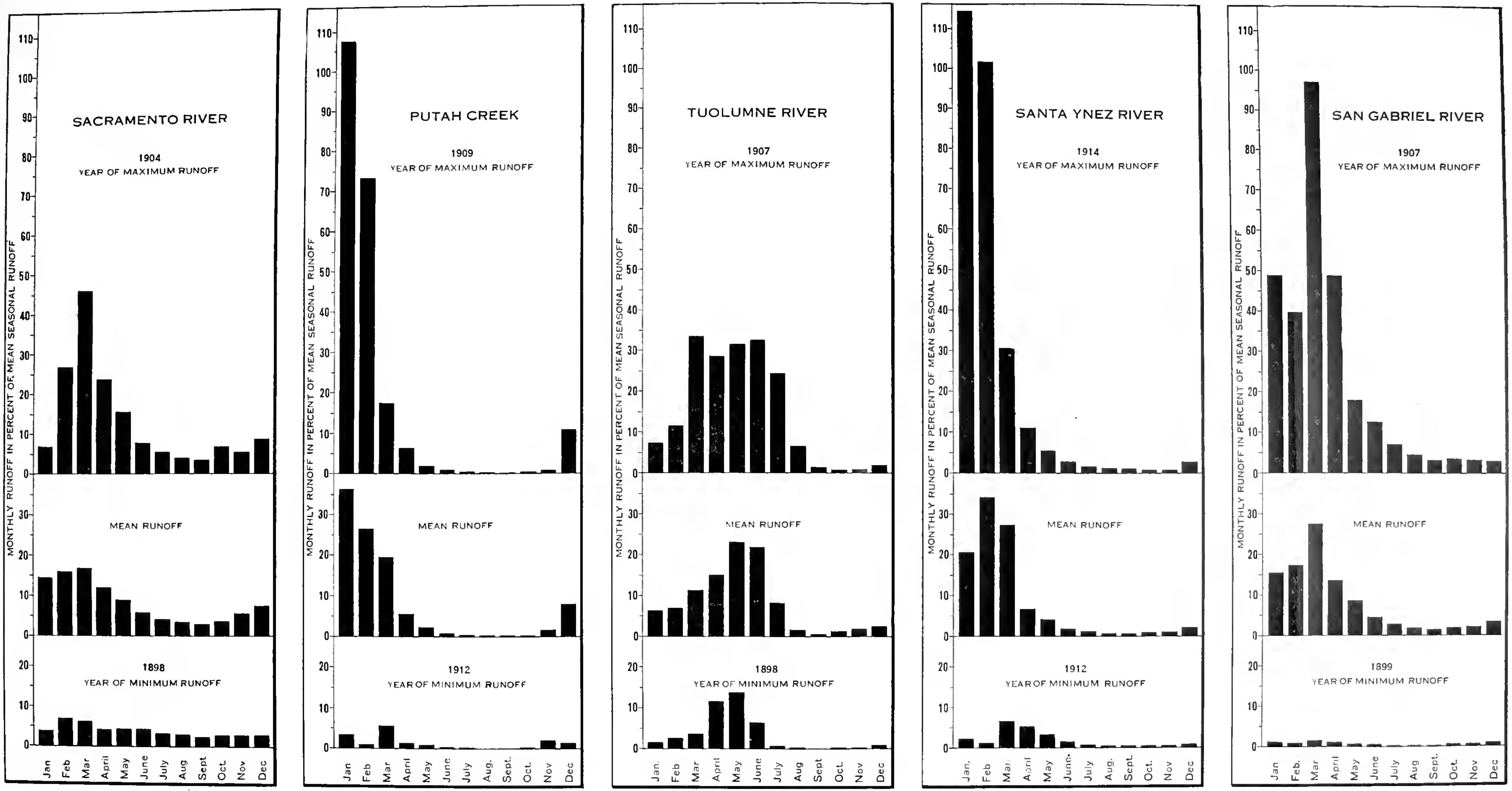
The first two columns of Table I contain the names of the streams or groups of minor streams and their reference numbers. Through these reference numbers, information that is too voluminous to incorporate in this summary tabulation may be conveniently traced in the diagrams and tables of Appendix "A" to this report. Spread out in forty columns to the right of these first two panels are values which characterize the amounts of water in each stream and its variability of flow.

Of these columns, the third contains the areas of the drainage basins, while in the fourth to the twelfth are values of their run-off expressed in a variety of units. Included among these entries are the quantities of water running off their collecting areas in an average season, and in the seasons of greatest and least run-off. These quantities affixed to each stream definitely locate all the state's waters. The mean seasonal quantities express the average amounts in which they may be expected to appear and constitute a statement of practically all existing waters, while the values for the extreme seasons show the limits between which the flow of successive seasons may vary.

While the average annual water production of all these streams is 72,500,000 acre-feet, this invoice of California's waters shows that the combined maximum yield is two and three-quarters times this amount, and that the combination of all streams for the least seasons is but three-eighths as much as the average annual amount. The total run-off in successive seasons, then, fluctuates between limits, one seven times the other, and the value of any one season lies at random between them.

In addition to changing from year to year, all the streams of the state have a fluctuating daily flow. Inclusions have been made in columns 13 to 18, and 35 to 42, of Table I, to define the extremes between which the daily flows are accustomed to range. Columns 13 to 18 give values to the run-off during the months of July and August. These two midsummer months are times of the year of nearly the least flow, and in which water is of much value agriculturally. The quantities include the entire month's run-off expressed in acre-feet, and when divided by sixty afford approximate values of the average daily flow during the low water periods in cubic feet per second. Contrasting them, are the values of flood flows in columns 35 to 42. These entries are of special import in not only indicating the upper limits of variability in stream flow, but also in indicating the maximum


MONTHLY RUNOFF IN PERCENT OF MEAN SEASONAL RUNOFF



STATE DEPARTMENT OF PUBLIC WORKS
DIVISION OF ENGINEERING AND IRRIGATION
CALIFORNIA WATER RESOURCES INVESTIGATION
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CHARACTERISTICS OF RUNOFF FROM CALIFORNIA MOUNTAINS

volumes of water which flood protection works may have to withstand. Comparisons of these flood values with the low water flows of July and August disclose a surprisingly great range in the rate of flow in California's streams.

As an average over the whole state, the greatest daily flow exceeds five hundred times the least. In taking values between these wide limits on every day of the successive years, the greater flows exceed the lesser ones in all degrees of magnitude, but the very large ones are the most infrequent in occurrence. To give perspective to the occurring frequency of exceedingly great flows, the values that may be surpassed within intervals of twenty-five, fifty, seventy-five, and one hundred years, are tabulated in columns 35 to 42. These greatest values of mean daily flow constitute the floods of California's streams. It is to be observed in general, that once in twenty-five years, the extraordinary values of daily flow swell at least forty fold the average volume in their channels; and that once in a hundred years, even these may be exceeded by flows that are one-quarter larger.

So large are the volumes of water that pass down the state's waterways during these great floods that the rate, which is only exceeded on an average of four times a century, would send a plethora of waters into the ocean within four days, whose aggregate is equivalent to the entire production of every drainage basin in the state for their seasons of least flow. During but one of these days, the total flow would be ample to supply an urban population of seventy millions of people with domestic water for a year, or to irrigate four million acres of agricultural land through an entire season, or, still, to generate one hundred thousand horsepower continuously for twelve months when dropping through a height of one hundred feet. Nevertheless, these volumes of water are largely useless to man because of their extremely infrequent appearance in the stream channels. The waters of lesser floods, however, may be caught by storage works constructed in the mountainous regions and be detained for later release to supplement the waning natural flow in the streams. By such detention of the flood waters for subsequent use, the erratic run-off may be equalized and made available to man at times convenient to his special purposes.

The greatest fractions of the mean seasonal flow which may be constrained to man's service through retention in storage reservoirs, are set forth for all the streams, in column 20 of Table I, and in column 21 are found the storage capacities required to do this. The yields from lesser amounts of storage are given in columns 23 to 34. The maximum yield possible from the entire water-producing area of the state is 58,300,000 acre-feet annually, or 80 per cent of the mean seasonal run-off. To secure this maximum yield would require a total capacity in storage works of 184,900,000 acre-feet. This volume is slightly greater than three times the annual equalized yield. Such large proportional amounts of storage are not needed if smaller fractions only of the mean seasonal flow are equalized. Capacity for storage of twice the net annual yield, will develop 70 per cent of the mean annual run-off from the state's drainage areas, and when this capacity is just equal to the annual yield in volume, it will develop 40 per cent of the mean seasonal run-off.

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All these hydrographic quantities of Table 1, while having characteristics which qualify the state's waters as a whole, vary considerably for the separate drainage basins. Nevertheless, adjacent basins are sufficiently alike to render distinction to whole regions by reason of their special values. These regional values, in departing from the ones for the entire state, are still only indicative of the predominating characteristics of large areas. Individual basins within the regions may have features widely different from those predominating over them.

The six large topographic divisions of the state have such predominant regional characteristics. Of these, the Sacramento Drainage Basin is the largest. It comprises not only all the area lying between the Coast Range and Sierra Nevada Mountains as far south as Suisun Bay, but also the drainage area of Pit River, to the east of the mountains and in the northeastern corner of the state. This large basin contains one-fourth of the state's water-producing area, and, with the exception of the North Pacific Coast region, it produces more than any other of the six divisions and one-third of all California's waters.

The San Joaquin Drainage Basin is second largest of the six topographical divisions, but produces only one-sixth of the waters. This basin comprises the entire area between the Coast Range and Sierra Nevada Mountains, southerly from Suisun Bay to Tehachapi Pass.

The third largest division is the North Pacific Coast region, which includes all the streams draining in the Pacific Ocean northward from San Francisco Bay. It contains only one-fifth of the water-producing area, but its streams contain over one-third of all the waters of the state. This is a greater yield than in any other of the divisions. For equal area it produces one-third more water than the Sacramento Basin and over twice that of the San Joaquin. This region contains the most productive drainage basin in the state, the Smith River. Although its collecting area is only 627 square miles in extent, the mean annual run-off is nearly three and one-half million acre-feet.

The region that drains into the Pacific Ocean, southward from San Francisco Bay, is called the South Pacific Basin, and for its size is the region of smallest water yield. Although containing one-sixth of the drainage area, but one-twentieth of the state's waters run off its slopes.

Next in size is the region of the Great Basin, which comprises the areas easterly from California's principal mountain system, and whose waters do not reach the ocean. One-tenth of the water-producing area of the state is in this region but it yields only one-twentieth of the waters: its increment in total is about equal to that of the South Pacific region.

The smallest of the six topographic divisions is the area adjacent to San Francisco Bay, exclusive of the Sacramento and San Joaquin rivers. This locality contributes only 1 per cent of the total waters of the state.

There is a great difference between these six regions in the manner in which their waters run off the collecting areas. Generally the regions of least productivity have the greatest variability in run-off and demand the largest capacities in storage works to equalize their variable stream flow. The South Pacific, the least productive of the six state regions, requires almost three times the storage capacity necessary to obtain the same relative effects in equalized stream flow, as the North Pacific region, the most productive of the six state regions.

TABLE 1. WATER RESOURCES OF CALIFORNIA.

Number of drainage basin. (1)	Stream. (2)	Area of drainage basin above main body of agricultural lands, in square miles (3)	Seasonal run-off from drainage area above the main body of agricultural lands — For year of mean run-off: Total in acre-feet (4)	Average acre-feet per square mile of drainage area (5)	Average depth in inches on drainage area (6)	For year of maximum run-off: Total in acre-feet (7)	Average acre-feet per square mile of drainage area (8)	Average depth in inches on drainage area (9)	For year of minimum run-off: Total in acre-feet (10)	Average acre-feet per square mile of drainage area (11)	Average depth in inches on drainage area (12)	Run-off during July: Mean of all months of July, acre-feet (13)
	SACRAMENTO BASIN											
34	Sacramento River (Upper) above Pit River	568	1,486,300	2,616	49.1	1,500,900	6,162	115.5	873,600	1,010	[illegible]	31,200
35	Pit River	5,346	4,204,600	786	14.7	6,220,000	1,165	25.5	2,455,200	461	[illegible]	[illegible]
36	McCloud River	669	1,591,200	2,378	44.1	3,270,000	4,885	91.5	800,600	1,197	[illegible]	[illegible]
37	*Churn Creek Group	100	53,100	[illegible]	[illegible]	204,500	2,045	[illegible]	3,200	32	[illegible]	[illegible]
38	Cow Creek	444	510,200	1,150	[illegible]	1,531,100	3,452	64.7	15,500	35	[illegible]	[illegible]
39	*Bear Creek Group	137	103,700	756	[illegible]	312,900	2,280	42.7	1,400	10	[illegible]	[illegible]
40	Battle Creek	366	421,500	1,151	[illegible]	1,025,700	2,799	52.5	138,500	377	[illegible]	[illegible]
41	Inks Creek	34	28,200	825	[illegible]	96,100	2,821	52.9	200	6	[illegible]	[illegible]
42	Paynes Creek	91	84,200	1,045	[illegible]	[illegible]	3,208	60.1	7,700	96	[illegible]	[illegible]
43	*Buckhorn Creek Group	172	[illegible]	1,166	[illegible]	[illegible]	3,609	67.7	[illegible]	11	[illegible]	[illegible]
44	Clear Creek	251	294,900	1,172	[illegible]	830,900	3,309	63.6	[illegible]	173	3.2	6,200
45	Cottonwood Creek	917	913,400	974	[illegible]	2,697,100	2,577	53.4	104,400	111	2.1	10,200
46	Sacramento River at Red Bluff	9,255	9,929,000	1,073	[illegible]	22,700,000	2,452	46.0	4,005,500	437	8.2	307,200
47	*Mill Creek Group	971	1,137,400	1,192	[illegible]	2,610,000	2,688	50.4	513,000	528	9.9	46,500
48	*Butte Creek Group	251	358,400	1,425	[illegible]	839,000	3,343	62.7	142,000	566	10.6	[illegible]
49	Feather River	3,627	5,253,500	1,456	[illegible]	[illegible]	[illegible]	62.5	2,073,900	572	10.7	[illegible]
50	*Honcut Creek Group	314	197,400	630	[illegible]	522,000	1,664	31.2	57,000	155	[illegible]	1,600
51	Yuba River	1,200	2,652,600	2,210	41.4	6,176,000	5,147	96.5	998,400	832	15.6	63,000
52	Dry Creek	79	49,700	627	[illegible]	137,300	1,715	32.2	14,800	187	3.5	[illegible]
53	Bear River	262	412,500	1,574	[illegible]	1,117,900	4,267	80.0	118,800	453	8.5	4,125
54	*Coon Creek Group	210	34,100	162	3.0	124,200	591	11.1	6,700	32	0.6	0
55	American River	1,919	3,154,900	1,658	[illegible]	7,725,200	4,026	75.5	1,159,900	615	11.6	117,700
56	*Red Bank Creek Group	109	73,000	672	[illegible]	202,900	1,861	34.9	20,000	187	3.5	510
57	*Elder Creek Group	414	213,000	515	[illegible]	611,000	1,476	27.7	57,000	138	2.6	1,190
58	Stony Creek	710	555,000	782	[illegible]	1,495,500	2,106	39.5	124,000	171	[illegible]	[illegible]
59	*Willow Creek Group	304	92,200	244	[illegible]	205,000	672	12.0	27,000	68	1.3	670
60	Cache Creek	1,125	546,000	490	[illegible]	1,634,000	1,371	25.7	151,000	146	2.7	[illegible]
61	Putah Creek	655	421,500	644	[illegible]	1,249,000	[illegible]	35.5	17,000	26	0.5	1,270
	Totals and means for Sacramento Basin	21,420	25,199,500	1,176	—		2,777	52.1		[illegible]	[illegible]	
	SAN JOAQUIN BASIN											
62	*Orestimba Creek Group	1,340	110,500	83	[illegible]	450,200	336	6.3	0	0	0.0	1,500
63	Panoche Creek	295	27,100	92	[illegible]	105,500	355	6.7	0	0	0.0	1,170
64	*Cantua Creek Group	205	12,500	60	[illegible]	55,500	267	5.0	0	0	0.0	540
65	Los Gatos Creek	119	9,750	82	[illegible]	41,300	347	6.5	0	0	0.0	420
66	*Tejon Creek Group	1,341	95,000	71	[illegible]	414,900	309	5.8	0	0	0.0	[illegible]
67	Caliente Creek	471	45,000	96	[illegible]	203,000	427	8.0	0	0	0.0	1,900
68	Kern River	2,410	760,400	316	[illegible]	2,471,500	1,027	19.2	281,000	117	2.2	82,000
69	*Poso Creek Group	676	[illegible]	62	[illegible]	184,100	320	6.0	0	0	0.0	[illegible]
70	Deer Creek	110	20,650	187	[illegible]	67,000	608	11.4	4,100	17	0.7	[illegible]
71	Tule River	390	141,500	363	[illegible]	448,500	1,152	21.6	27,000	69	1.3	[illegible]
72	*Yokohl Creek Group	98	14,800	151	[illegible]	58,500	[illegible]	11.2	0	0	0.0	[illegible]
73	Kaweah River	514	407,900	794	[illegible]	[illegible]	2,115	39.7	[illegible]	[illegible]	1.8	[illegible]
74	[illegible] Creek Group	201	62,200	310	[illegible]	195,100	[illegible]	18.5	7,500	37	0.7	2,700
75	Kings River	1,694	1,925,100	1,136	[illegible]	5,221,000	3,082	57.8	[illegible]	[illegible]	3.7	221,400
76	Dry Creek	48	4,509	94	[illegible]	18,100	[illegible]	7.1	0	0	0.0	100
77	San Joaquin River (Upper)	1,631	2,056,000	1,263	[illegible]	[illegible]	[illegible]	65.9	470,000	[illegible]	5.4	[illegible]
78	Cottonwood Creek	25	2,300	91	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0.0	[illegible]
79	Fresno River	270	68,300	253	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15	0.3	[illegible]
80	*Daulton Creek Group	66	5,200	75	[illegible]	21,100	[illegible]	[illegible]	0	0	0.0	[illegible]
81	Chowchilla River	235	67,700	[illegible]	[illegible]	195,100	830	15.4	1,200	5	0.1	[illegible]
82	*Dutchman Creek Group	72	6,300	[illegible]	[illegible]	31,500	[illegible]	8.2	0	0	0.0	100
83	Mariposa Creek	103	12,900	125	[illegible]	48,200	469	8.8	0	0	0.0	290
84	*Owens Creek	66	6,500	[illegible]	[illegible]	27,900	421	7.9	0	0	0.0	150
85	Bear Creek	71	7,500	105	2.0	29,700	418	7.8	0	0	0.0	170
86	*Burns Creek Group	171	24,400	143	2.7	80,200	469	8.8	0	0	0.0	[illegible]
87	Merced River	1,054	1,131,500	1,075	20.2	[illegible]	[illegible]	[illegible]	220,000	209	[illegible]	99,800
88	Tuolumne River	1,543	2,035,500	1,332	24.9	5,090,000	[illegible]	61.8	561,000	363	6.8	[illegible]
89	*Wildcat Creek Group	59	[illegible]	151	2.8	32,000	[illegible]	[illegible]	0	0	0.0	30
90	Stanislaus River	983	1,376,400	[illegible]	26.1	[illegible]	[illegible]	[illegible]	62,900	64	1.2	76,700
91	Little Johns Creek	41	8,150	201	3.8	28,700	[illegible]	13.3	400	10	0.2	20
92	*Martells Creek Group	122	14,300	117	2.2	[illegible]	[illegible]	6.9	0	0	0.0	10
93	Calaveras River	394	316,500	803	15.1	1,000,000	2,540	47.7	29,400	75	1.4	950
94	Mokelumne River	632	[illegible]	[illegible]	20.7	2,151,000	[illegible]	64.7	170,000	[illegible]	5.3	52,100
95	*Sutter Creek Group	285	93,300	[illegible]	6.1	277,000	971	18.2	0	0	0.0	250
96	Cosumnes River	534	[illegible]	903	16.9	1,412,000	2,644	[illegible]	108,000	202	3.8	[illegible]
	Totals and means for San Joaquin Basin	18,178	12,331,300	[illegible]	12.7		[illegible]	[illegible]		[illegible]	[illegible]	
	SAN FRANCISCO BAY BASINS.											
97	*Petaluma Creek Group	139	75,300	542	10.2	263,300	[illegible]	35.5	8,900	64	1.2	[illegible]
98	*Sonoma Creek Tributaries	73	36,600	[illegible]	[illegible]	124,400	[illegible]	[illegible]	7,900	104	1.9	110
99	*Napa River Tributaries	226	115,200	510	9.6	419,400	1,856	34.8	9,600	42	0.8	[illegible]
100	*Suisun Creek Group	125	52,500	[illegible]	7.9	[illegible]	[illegible]	28.7	10,600	85	1.6	160
101	*Mt. Diablo Creek Group	200	69,600	[illegible]	6.6	262,900	1,317	24.7	1,100	6	0.1	300
102	San Pablo Creek	41	17,200	[illegible]	7.9	[illegible]	[illegible]	27.5	0	0	0.0	90
103	San Leandro Creek	44	18,900	[illegible]	8.1	70,900	1,620	[illegible]	0	0	0.0	[illegible]
104	*Claremont Creek Group	84	24,600	[illegible]	[illegible]	[illegible]	[illegible]	26.2	0	0	0.0	[illegible]
105	San Lorenzo Creek	38	16,700	[illegible]	8.3	63,700	[illegible]	[illegible]	200	5	0.1	[illegible]
106	Alameda Creek	651	140,900	215	4.0	547,200	837	15.7	0	0	0.0	1,500
107	*[illegible] Creek Group	77	25,000	[illegible]	6.1	[illegible]	[illegible]	28.0	0	0	0.0	130
108	Penitencia Creek	22	5,200	[illegible]	4.4	[illegible]	1,013	19.0	200	9	0.2	[illegible]
109	Coyote River	197	[illegible]	407	7.6	[illegible]	[illegible]	33.5	0	0	0.0	400
110	Guadalupe River	52	22,000	421	7.9	[illegible]	1,814	34.0	0	0	0.0	[illegible]
111	*Los Gatos Creek Group	121	68,500	566	10.6	219,400	1,813	34.0	0	0	0.0	340
112	San Francisquito Creek	38	20,700	[illegible]	10.3	[illegible]	1,707	32.0	800	21	0.4	100
113	*San Mateo Creek Group	84	37,100	[illegible]	8.2	129,300	1,531	28.7	3,600	43	0.8	[illegible]
	Totals and means for San Francisco Bay Basins	2,219	825,300	[illegible]	7.0		[illegible]	[illegible]		[illegible]	0.4	
	NORTH PACIFIC BASINS.											
114	Smith River	627	3,406,200	5,433	101.9	5,711,600	9,109	[illegible]	[illegible]	3,067	57.5	64,700
115	Klamath River	2,320	3,410,700	1,470	27.6	7,100,900	3,061	57.4	[illegible]	525	[illegible]	[illegible]
116	Shasta River	603	242,600	402	[illegible]	[illegible]	830	[illegible]	[illegible]	[illegible]	[illegible]	17,000
117	Scott River	813	521,100	641	12.0	1,233,100	1,517	[illegible]	172,200	212	4.0	[illegible]
118	Salmon River	734	1,256,400	1,712	32.1	2,466,200	3,360	63.0	508,900	[illegible]	13.0	47,700

99	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
100	*Suisun Creek Group	125	52,500	421	7.9	190,200	1,330	[illegible]	1,100
101	*Mt. Diablo Creek Group	200	69,800	350	6.0	262,900	1,317	24.7	
102	San Pablo Creek	41	17,200	424	7.9	59,500	1,466	47.5	0
103	San Leandro Creek	44	18,500	350	5.1	70,000	1,626	30.5	0
104	*Claremont Creek Group	83	24,600	297	5.0	115,900	1,397	26.2	0
105	San Lorenzo Creek	35	16,700	441	8.3	64,700	1,081	41.5	200
106	Alameda Creek	654	140,900	216	4.0	547,200	837	15.7	0
107	*Mission Creek Group	77	25,000	324	6.1	115,100	1,493	25.0	0
108	Penitencia Creek	22	5,200	232	4.4	22,700	1,013	19.0	200
109	Coyote River	197	80,100	407	7.6	351,000	1,782	33.5	0
110	Guadalupe River	52	22,000	411	7.9	94,700	1,814	24.0	0
111	*Los Gatos Creek Group	121	68,500	566	10.6	219,100	1,813	34.0	0
112	San Francisquito Creek	38	20,700	550	10.3	64,200	1,707	32.0	500
113	*San Mateo Creek Group	54	37,100	439	8.2	129,300	1,531	28.7	3,600
	Totals and means for San Francisco Bay Basins	2,219	825,300	372	7.0		1,400	26.1	
	NORTH PACIFIC BASINS								
114	Smith River	627	3,306,200	5,433	101.9	5,711,600	9,109	170.8	1,922,800
115	Klamath River	2,320	3,410,700	1,470	27.6	7,100,000	3,061	57.4	1,219,000
116	Shasta River	803	242,600	302	5.7	590,000	735	13.8	102,500
117	Scott River	817	521,100	641	12.0	1,234,100	1,517	28.4	172,200
118	Salmon River	734	1,256,400	1,712	32.1	2,460,900	3,360	63.0	505,900
119	Trinity River	2,965	4,447,700	1,500	28.1	9,640,100	3,253	61.0	1,421,200
120	Redwood Creek	275	827,400	3,012	57.1	1,371,100	4,981	94.4	475,600
121	Mad River	457	1,152,500	2,588	48.5	1,995,600	4,372	82.0	548,400
122	Eel River	3,547	6,040,000	1,703	31.8	11,040,000	3,113	58.4	2,359,600
123	Bear Creek	82	227,000	2,755	52.2	392,500	4,816	90.3	119,500
124	Mattole River	264	1,060,600	4,017	75.3	1,528,900	6,925	129.9	756,400
125	*Noyo River Group	780	1,305,300	1,671	31.4	2,861,100	3,665	68.8	428,300
126	Navarro River	273	391,600	1,435	26.9	866,300	3,173	59.5	119,400
127	*Gualala River Group	623	849,700	1,364	25.6	1,840,500	2,955	55.4	272,500
128	Russian River	1,505	1,416,600	910	17.6	3,367,000	2,235	41.9	64,300
129	Lagunitas Creek	84	89,200	1,062	19.9	204,700	2,437	45.7	25,100
130	*Salmon Creek Group	250	113,300	453	9.3	284,600	1,237	23.2	24,500
131	*Bolinas Creek Group	155	36,600	[illegible]	4.3	107,000	677	12.7	7,600
	Totals and means for North Pacific Basins	16,540	26,835,400	1,622	30.4		3,199	60.0	
	SOUTH PACIFIC BASINS								
132	San Diego River	207	35,300	171	1.2	232,000	1,121	21.0	1,100
133	Santa Ysabel Creek	126	32,000	252	1.9	200,300	1,590	29.9	1,300
134	San Luis Rey River	125	59,100	163	3.4	451,300	1,173	22.0	3,500
135	Santa Margarita River	690	31,000	45	0.9	163,200	237	4.0	703
136	*San Jacinto River Tributaries	330	48,600	147	2.8	218,200	661	12.4	10,800
137	*Santa Ana River Tributaries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
138	*San Gabriel River Tributaries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
139	*Los Angeles River Tributaries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
140	*Malibu River Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
141	*Santa Clara River Tributaries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
142	Ventura River	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
143	*Jalama Creek Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
144	Santa Ynez River	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
145	San Antonio Creek	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
146	Santa Maria River	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
147	*San Luis Obispo Creek Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
148	*Salinas River Tributaries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
149	*Pajaro River Tributaries	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
150	*Soquel Creek Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
151	*Pescadero Creek Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Totals and means for South Pacific Basins	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	
	GREAT BASIN								
152	*Tule Lake Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
153	*Goose Lake Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
154	*Cowhead Lake Basin	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
155	*Surprise Valley Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
156	*Madeline Plains Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
157	*Smoke Creek Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
158	*Eagle Lake Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
159	*Honey Lake Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
160	*Lake Tahoe Basin	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
161	Truckee River	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
162	West Fork Carson River	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
163	East Fork Carson River	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
164	West Walker River	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
165	East Walker River	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
166	*Mono Lake Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
167	*Adobe Meadows Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
168	*Owens River (Upper)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
169	*Bishop Creek Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
170	*Owens Lake Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
171	Mojave River	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
172	*Antelope Valley Group	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
173	Whitewater River	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Totals and means for Great Basin	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	
	Grand totals and means for State	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	

†Sacramento River at Red Bluff includes all streams preceding it in the list, and its area includes 145 square miles additional. See Table 46.

*STREAMS GROUPED IN ONE ENTRY IN TABLE.

37 Churn Creek, Stillwater Creek.
39 Ash Creek, Bear Creek.
43 Backbone Creek, Rock Creek, Olney Creek.
47 Mill Creek, Deer Creek, Antelope Creek, Big Chico Creek, Little Chico Creek, Sycamore Hollow, Sheep Hollow, Grizzly Hollow, Mud Creek, Rock Creek, Pine Creek, Zimmershed Creek, Camel Creek, Rattlesnake Creek, Singer Creek, Brush Creek, Rio de Los Berrendos.
49 Butte Creek, Little Dry Creek, Clear Creek, Gold Run Creek, Chambers Ravine, Coal Canyon.
50 North Honcut Creek, South Honcut Creek, Wyman Creek, Wyandotte Creek, Dry Creek.
54 Coon Creek, Antelope Creek, Auburn Ravine.
56 Reeds Creek, North Fork Red Bank Creek, South Fork Red Bank Creek.
57 Elder Creek, Thomes Creek, Rice Creek.
59 Hambright Creek, Willow Creek, Logan Creek, Hunters Creek, Funks Creek, Stone Corral Creek, Sand Creek, Freshwater Creek, Salt Creek, Spring Creek, Cortina Creek.
62 Little Panoche Creek, Laguna Seca, Ortigalita Creek, Los Banos Creek, San Luis Creek, Romero Creek, Quinto Creek, Mustang Creek, Garzas Creek, Crow Creek, Orestimba Creek, Little Salada Creek, Salada Creek, Puerto Creek, Ingram Creek, Hospital Creek, Buenos Aires Creek, Mountain House Creek, Bushy Creek, Kellogg Creek, Marsh Creek, Lone Tree Creek, Sand Creek, Dry Creek, Deer Creek.
64 Domengine Creek, Martinez Creek, Salt Creek, Cantua Creek, Arroyo Hondo, Arroyo Ciervo.
66 Waltham Creek, Jacalitos Creek, Zapato Creek, Bitterwater Creek, Devil water Creek, Media Agua, Chico Martinez Creek, Salt Creek, Bitter Creek, Santiago Creek, Liveoak Creek, San Emigdio Creek, Pleito Creek, Tecuya Creek, Grapevine Creek, Pastoria Creek, Tunis Creek, El Paso Creek, Tejon Creek, Santos Creek, Caliente Creek, Garza Creek, Avenal Creek, Cottonwood Canyon, Franciscan Creek, Packwood Creek, Buena Vista Creek, Bitterwater Creek, Salt Creek.
69 White River, Poso Creek, Rag Gulch.
72 Yokohl Creek, Lewis Creek, Horse Creek.
74 Limekiln Creek, Rattlesnake Creek, Stokes Creek, Sand Creek, Wa-to-ke Creek, Granay Creek.
80 Dry Creek, Doulton Creek.
82 Dutchman Creek, Deadman's Creek.
84 Owens Creek, Miles Creek.
86 Burns Creek, Black Rascal Creek, Fahrens Creek.
89 Wildcat Creek, Dry Creek.
92 Martells Creek, Bear Creek, Rock Creek, Big Spring Creek, Peachys Creek.
95 Dry Creek, Willow Creek, Sutter Creek.
97 Novato Creek, Gallinas Creek, San Antonio Creek, Adobe Creek, Lynch Creek, Haggin Creek, Tolay Creek.
98 Lovall Valley, Agua Caliente, Rocker Creek, Stewart Creek, Nunn's Canyon Creek, Sonoma Creek, Sonoma Canyon.
99 Cuno Creek, Rector Canyon, Soda Creek, Milliken Creek, Sarco Creek, Tulucay Creek, Suisol Creek, Lake Chabot System, North Branch Napa Creek, South Branch Napa Creek, Dry Creek, Sulphur Springs.
100 Suisun Creek, Ulatis Creek, Ledgewood Creek, Green Valley Creek, Sulphur Springs Creek.
101 Kirker Creek, Mt. Diablo Creek, Walnut Creek, Rodeo Creek, Pinole Creek.
104 Wildcat Creek, Cerrito Creek, Strawberry Creek, Claremont Creek, Temescal Creek, Hayes Creek, Indian Creek, Diamond Creek, East Creek, Arroyo Viejo.
107 Mission Creek, Agua Caliente Creek, Agua Fria Creek, Toroges Creek, Scott Creek, Calera Creek, Arroyo de los Coches, Berryessa Creek, Dry Creek, Silver Creek.
111 Los Gatos Creek, San Tomas Creek, Campbell Creek, Calabazas Creek, Stevens Creek, Permanente Creek.
113 Islais Creek, San Bruno Creek, San Mateo Creek, Laurel Creek, Belmont Creek, Pulgas Creek, Cordilleras Creek.
125 Ind Creek, Wade Creek, Ten Mile Creek, Noyo River, Big River, Albion Creek.
127 Dunahoe Creek, Elk Creek, Alder Creek, Brush Creek, Garcia River, Gualala River.
130 Walker Creek, San Antonio Creek, Salmon Creek.
131 Bolinas Creek, Inverness Creek, Olema Creek.
136 San Jacinto River, Indian Creek, Poppett Creek, Potrero Creek, Bautista Creek, Cactus Valley Creek.
137 Santa Ana River, Mill Creek, Sand Creek, City Creek, Plunge Creek, Strawberry Creek, Waterman Canyon, Devil Canyon Creek, Cajon Canyon, Lone Pine Creek, Lytle Creek, San Antonio Creek, Cucamonga Canyon.
138 San Gabriel River, Eaton Creek, Little Santa Anita Creek, Santa Anita Creek, Sawpit Creek, Fish Creek, San Dimas Creek, Big Dalton Canyon.
139 Pacoima Creek, Tujunga Creek, Arroyo Seco, Little Tujunga Canyon.
140 Dume Creek, Ramera Creek, Solstice Creek, Callegas Creek, Sycamore Creek, Arroyo Sequit, Trancas Canyon, Malibu River, Topanga Creek, Rustic Creeks.
141 Santa Paula Creek, Sespe Creek, Piru Creek, Castaic Creek, San Francisquito Creek, Bouquet Creek.
144 Rincon Creek, San Antonio Creek, Jalama Creek, Honda Creek.
147 Grande Creek, San Luis Obispo Creek, Diablo Creek, Coon Creek, Islay Creek, San Bernardo Creek, Morro Creek, Toro Creek, Villa Creek, Santa Rosa Creek, San Simeon Creek, Arroyo de la Cruz, Big Sur Creek, Little Sur Creek, Carmel River, San Carpojo River, Corral de Piedra Creek, Brassolan Creek, Steiner Creek, Pennington Creek, San Lusito, Davis Canyon, Wild Cherry Canyon, Diablo Canyon, Harford Canyon, Crow Bar Canyon, Fish Creek, Willow Creek, Old Creek, Cuyamaca Creek, Pico Creek, Little Pico Creek, Sierra Creek, Arroyo Hondo, Arroyo de los Chinos, Joshua Creek, Salmon Creek, Villa Creek, Alder Creek, Willow Creek, Prewlitt Creek, Wild Cattle Creek, Mill Creek, Palo Colorado Canyon, Dead Creek, Wild Cat Creek, Granite Canyon, Malpaso Creek, Soberanes Creek.
148 Toro Creek, Pine Canyon, Limekiln Creek, Alisal Creek, Quail Creek, Paraiso Creek, Johnson Canyon, Arroyo Seco, Reliz Creek, Shirttail Creek, Chalone Creek, San Carlos Canyon, Agua Grande Canyon, Monroe Canyon, Thompson Canyon, Branstetter Canyon, Pine Canyon, Cherry Canyon, Kent Canyon, Seven Well Canyon, Tela Canyon, Lapunes Canyon, Broadhurst Canyon, Barrel Canyon, San Lorenzo Creek, Sweetwater Canyon, Wild Horse Canyon, Hamilton Canyon, Long Valley Creek, Pine Valley Creek, Redwood Canyon, Lynch Canyon, Sargent Canyon, Salinas River, San Antonio Creek, Nacimiento River, San Marcos Creek, Huerhuero Creek, Estrella Creek, Vineyard Canyon, Stone Canyon.
149 Pescadero Creek, La Brea Creek, Bodfish Creek, Little Arthur Creek, Uvas Creek, Llagas Creek, Pacheco Creek, Arroyo de las Viboras, Arroyo dos Pichacos, Santa Ana Creek, Tres Pinos Creek, San Benito Creek, Bird Creek, San Juan Creek.
150 San Vicente Creek, Liddell Creek, Respini Creek, Laguna Creek, Coja Creek, Baldwin Creek, Moore Creek, Arroyo de los Frijoles, White House Creek, Cascade Creek, Green Oaks Creek, Ano Nuevo Creek, Finny Creek, Gazos Creek, Waddell Creek, Scott Creek, San Lorenzo Creek, Soquel Creek, Aptos Creek.
151 Pilarcitos Creek, Purisima Creek, Tunitas Creek, San Gregorio Creek, Pomponio Creek, Pescadero Creek, Lobitos Creek, Frenchman's Creek, Denniston Creek, San Vicente Creek, San Pedro Creek.
152 Butte Creek, Antelope Creek, Cottonwood Creek, Lost River.
153 Cottonwood Creek, Myrtle Creek, Fandango Creek, Lassen Creek, Davis Creek.
154 Eight Mile Creek.
155 Dry Creek, Cottonwood Creek, Owl Creek, Raider Creek, Eagle Creek, Barns Creek.
156 Red Rock Creek, Cold Springs Creek, Van Loan Creek.
157 Smoke Creek, Rush Creek.
158 Pine Creek.
159 Susan River, Baxter Creek, Long Valley Creek.
160 Meigs Creek, Ward Creek, Blackwood Creek, Madden Creek, McKinney Creek, General Creek, Lonely Gulch, Upper Truckee River, Taylor Creek.
166 Mill Creek, Gibbs Canyon, Leevining Creek, Parker Creek, Rush Creek, Walker Canyon.
167 Chidago Canyon, Montgomery Creek, Marble Creek, Coldwater Canyon, Lone Tree Creek, Milner Creek, Piute Creek, Birch Creek, Willow Creek, Sacramento Canyon, McGee Canyon, Black Canyon.
168 Owens River (Upper), Rock Creek.
169 Pine Creek, Huckleberry Creek, Horton Creek, McGee Canyon, Birch Creek, Bishop Creek, Rawson Creek, Freeman Creek, Shannon Creek, Baker Creek, Big Pine Creek, Little Pine Creek, Birch Creek, Fuller Creek, Tinemaha Creek, Red Mountain Creek, Taboose Creek, Goodale Creek, Division Creek, Sawmill Creek, Thibaut Creek, Oak Creek, Independence Creek, Pinyon Creek, Symmes Creek.
170 Shepard Creek, Bairs Creek, George Creek, Hogback Creek, Lone Pine Creek, Tuttle Creek, Diets Creek, Richer Creek, Carrol Creek, Cottonwood Creek, Ash Creek, Braley Creek, Carthage Creek, Blancha Creek, Walker Creek, Summit Creek, Harvey Creek, Hogback Creek.
172 Amargosa Creek, Little Rock Creek, Big Rock Creek.

Of the basins of intermediate water productivity, the Sacramento and San Joaquin are about equal in relative storage requirements. Although the streams of the San Joaquin drainage have a much greater range in variation of annual run-off than those of the Sacramento, the bulk of the San Joaquin waters run off later in the season than those of the Sacramento, and so, in general, storage works are about equally effective in each basin. These two basins require slightly less storage capacity for equal relative results to that required by the North Pacific region, for the North Pacific region has the smaller summer flow in its streams. However, the relative storage requirements in these three regions are nearly alike.

The San Francisco Bay region, because of its smaller fluctuation in annual run-off than the South Pacific, and greater than the Sacramento or San Joaquin, falls intermediate in effectiveness of storage on its streams, between the South Pacific region and the three greatest water producing basins of the state, in which storage capacity, on the whole, is nearly equally effective. Almost twice as much capacity in storage works is necessary in the San Francisco Bay region to gain equal relative results in equalizing its stream flow as in either of the Sacramento or San Joaquin basins.

The relative amounts of storage required to equalize stream flow, largely pertain to the range in variation between years of maximum and minimum run-off and to the apportionment of the annual run-off between the winter and summer months. The North Pacific region has the smallest variation in annual run-off, and there the maximum is only five times that of the minimum season. The maximum year in the Sacramento Basin is six times the least, while in all the other regions the variation is much larger than in these two. In the San Joaquin it is fifteen times the least, in the San Francisco Bay region it is seventy times the least, and in the South Pacific the year of maximum run-off is one hundred times the least year.

While the San Francisco Bay region has the smallest portion of its waters wetting the stream channels during the summer months, the Great Basin drainage, east of the Sierras and southern California mountains, is distinguished by having the largest apportionment of summer flow of any of the six regions. The streams of the San Joaquin Basin are next in order and those of the Sacramento not far behind. The North Pacific region has an intermediate apportionment in the summer months between that of the San Joaquin and that of the South Pacific region.

Similar comparisons may be made between any of the individual drainage basins in the state by referring to Table I in the proper columns. The flow in all streams during the largest, the smallest, and the average season, as well as during the midsummer months, is there. Also the storage capacity required to equalize their variant flows and the size of extreme floods are enumerated. So, comprised within Table I, is a complete inventory of all the waters of the state, which includes their locations, their quantities and their variabilities. The values entered in the table are averages for the past half century and should be indicative of future expectancies, so that this table presents in full the water resources of the State of California with their characterizations.

CHAPTER V.

UTILIZATION OF THE STATE'S WATERS.

Only one-half of the wide expanse of California contributes much to the waters of its streams. The other half, lower in altitude and more even of surface, is favorably disposed for occupancy by man, and its populated sections need water in order that their industrial expansion may continue and their communal civilization progress steadily onward. The production of food, the generation of power, and the supply of water for domestic use, in the drier half of the state, are largely dependent upon the waters of the streams which have their source in the more elevated regions. The farmer relies upon the streams during the warm, dry summers for supplementary moisture to mature his crops and upon their hydro-electric energy to pump his irrigation waters. The electric energy, generated by the waters of the streams as they descend the mountains' slopes, furnishes power and illumination to the industrial centers, and light and heat and means of operating many conveniences, to the entire social state. But most of all, the cities, towns, and villages, the pleasures and comforts of their congregated peoples, require these waters in abundance for drinking and household purposes. The expansion of all these benefits to include larger populations, demands increased supplies of water for the future with uninterrupted service in purity and plenty, at all times of the year, and in all successive years alike.

The vital importance of water in the economic development of California is succinctly shown in the history of the state's production. By 1920, with but three per cent of all the people in the entire United States residing within California's borders, this state, eighteenth in the area of land farmed, was fifth in position among the states of the Union in value of farm crops; and while in the eighth position in value of manufactures, was second in the installed capacity of water wheels for the hydro-generation of electric current. Since 1920, this state has advanced from fifth to fourth[1] among the states of the Union in value of agricultural products.

The advance to so favorable a comparison in agricultural output with the other forty-seven states of the Union, has been made without any increase in the total area in improved farms. In fact, thirty-five years have elapsed since the aggregate area in improved farms in California has increased. Although there are twenty-three million acres of land susceptible of agriculture within the state's borders, the enlargement of the area tilled ceased when but half of the total had been brought under cultivation. As a result of the unprofitable farming conditions obtaining on the remaining millions of acres, the area under cultivation did not further enlarge; the experience of the practical farmer limited the total area cultivated to but half the agricultural lands. Some

[1]Statistics of California State Department of Agriculture show that this state was exceeded in value of agricultural products by Texas, Iowa and Illinois.

additional areas having inadequate natural moisture have since been added to the total area of improved farms by developing accessory water supplies, but the abandonment of other areas previously farmed has compensated in their summation so that the total acreage in improved farms has remained practically unchanged for thirty-five years.

This limit to the area in improved farms was reached in the year 1885. Prior to this year, the tilled area had expanded in leaps and bounds from the great impetus to farming enterprises that followed the world wide movement to this state after the discovery of gold at the midway point of the last century. This enlargement of the farmed area continued at a rapid rate for a third of a century, then slackening, it ceased about 1885.

With less than 12,000,000 acres cultivated, all of the state's agricultural area with sufficient natural moisture to mature a profitable crop had been brought into use. Since 1885, the state has had no additional area that could be profitably utilized for agriculture in its natural condition, so that in response to the continuing favorable market for agricultural products, a more intensive farming of the land already under cultivation has been in progress. All through these thirty-five years, the demand for products of California's agriculturists has never ceased to increase at an accelerated rate. California, favorably situated, its fertile agricultural soils producing to capacity under conditions of dry farming, required only that additional water be applied to these lands to multiply their yield. The practical farmer, answering to the ever-enlarging market for his products, increased the yield of many acres by supplementing the soil's natural moisture with water applied through irrigation. In this way the state has continued, through the last thirty-five years, to respond to the constantly increasing demand for its farm products, and in this way the potent possibilities of California's farm lands are being invoked to a yield greater in value than in any other state of the Union.

The utility of the state's waters in augmenting the yield of its agricultural lands and the demands of the future, may best be ascertained through an investigation of the use of water in the past. The quantity of accessory water needed for growing crops to an harvestable maturity, may best be derived from the results of experience and practice. California's lands, deficient in natural moisture during the growing season of agricultural plants, have received varying quantities of water. The amounts applied on the sundry tracts in the divers localities, differ widely with all the circumstances and conditions affecting the use of water. The application to different fields has varied greatly even for like crops, for not only do the quantities of water used vary with the incentive for their economic application, but the amounts that are dissipated in the process of irrigation change greatly with contingent circumstances, and even the actual quantity necessary for absorption by the root systems of the plants, is conditional.

These circumstances and conditions necessitating the application of more or less accessory water, are so vast in number, changing with every variation in soil, crop, and preparation for spreading water, that on small tracts of land, the effect of one may predominate, but on greater areas they tend to neutralize in effect. For this reason the average use of water on very large areas approaches like figures, while the use on small tracts within these large areas, may take wide numer-

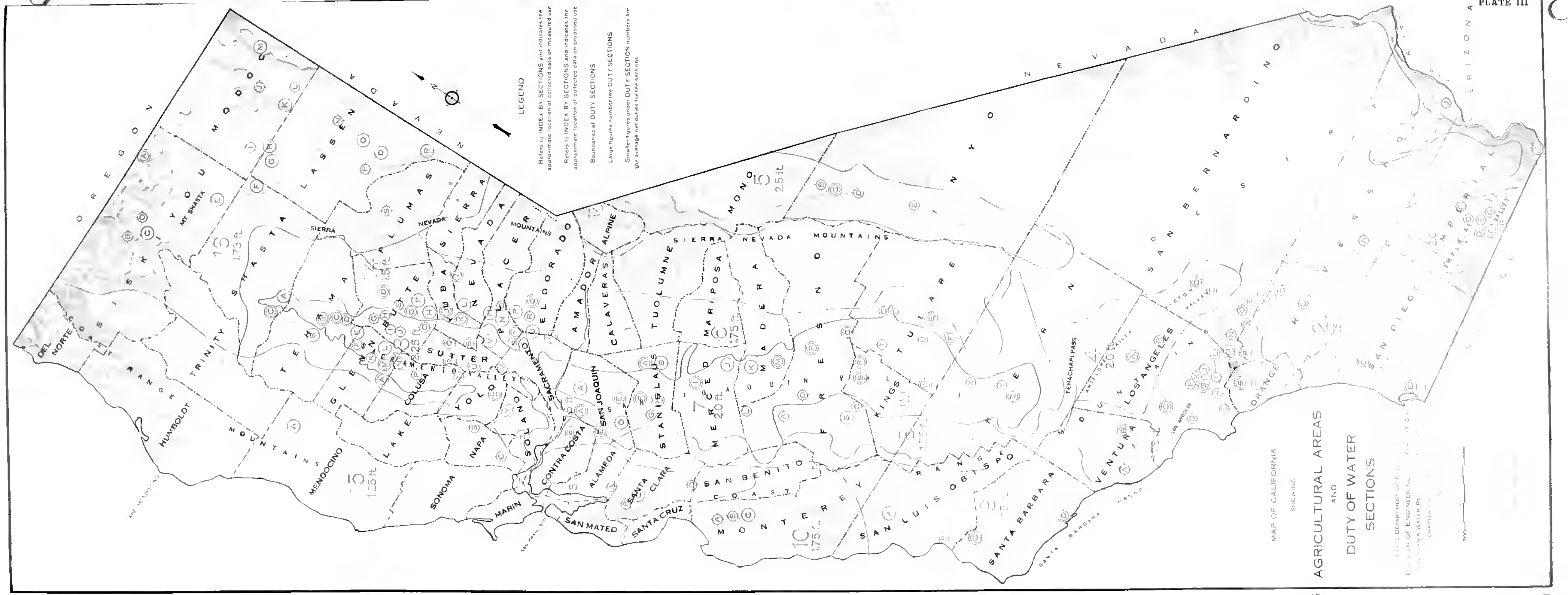
ical departure from the general average. The larger the areas compared, usually the closer is the agreement of numerical values in the records of use. From the average use of water on large areas, sufficiently great to suppress the predominance of effects peculiar to small parcels, natural divisions of the state, sixteen in number, have been evolved, and called duty of water sections. These sections comprise within their boundaries, lands of approximately like geographic position, similar surface conformation, of analogous economic environment, and equal climate, and so form convenient segregations for the disclosure of the irrigation requirements of California's agricultural lands.

Delineated on Plate III, "Map of Agriculture Areas and Duty of Water Sections," the boundaries of these sections show as red lines following natural dividing conformations of the land surface. The agricultural lands show as light green areas within the delimiting red lines. Letters within circles, interspersed throughout the green areas, indicate the location of individual irrigation systems or of divers tracts of land for which data on the actual use of water or on proposed uses, have been collected by these investigations. A searching inquiry of the use of water has been made and water measurements have been assembled applying to an area that equals more than half the lands irrigated in the entire state during 1919. These records are the summation of the labors of a great many engineers and hydrographers that cover the major portion of the last two decades. These extensive data are included with pertinent material in Appendix "B" to this report and the letters within the circles on the map, are attached to the data on the plates and in the tables of this appendix, so that the approximate geographic situation of the lands to which the data apply may be traced.

That the water requirements for each of the several sections of the state might be derived from this great assemblage of information, an examination of the circumstances and a close scrutiny of the conditions were made, surrounding the use of water in each section. All information on the types and fertility of soils, the crops grown, the climate, the water supply, the surface conformation of the land, and all other subjects related to irrigation requirements, was reviewed and compared with the measured and proposed uses of water. Practical working quantities required of accessory water supplies in each section, were so evolved and recorded in Table 2, "Agricultural Area and Net Duty of Water in the Sixteen Sections of California." The total area of agricultural land in each section is also recorded in this table and numbers are given to each section that show their location on the map, Plate III.

These practical working quantities in Table 2 that set forth the general water needs of the agricultural areas in each section, are expressed as the amount of water required on a unit area of cropped land and are named the "Duty of Water." Originally an expression for the area of land that a measure of water would irrigate when flowing continuously through the irrigation season, custom has inverted the first meaning and more conveniently utilizes the term "Duty of Water" to name the quantity of irrigation water required to furnish throughout one season, an adequate supplementary supply to the soil moisture on a unit area of land. This quantity is usually expressed as feet-depth on the land, meaning the depth that the total amount of water required each year for one acre, would cover its surface if it

PLATE III



MAP OF CALIFORNIA
SHOWING
AGRICULTURAL AREAS
AND
DUTY OF WATER
SECTIONS
LEGEND
Refers to INDEX BY SECTIONS and indicates the approximate location of collected data on measured use
Refers to INDEX BY SECTIONS and indicates the approximate location of collected data on proposed use
Boundaries of DUTY SECTIONS
Large figures number the DUTY SECTIONS
Smaller figures under DUTY SECTION numbers are the average net duties for the sections
OREGON
NEVADA
ARIZONA
DEL NORTE
SISKIYOU
MODOC
MT SHASTA
LASSEN
SHASTA
TRINITY
HUMBOLDT
TEHAMA
PLUMAS
SIERRA
NEVADA
GLENN
BUTTE
YUBA
SUTTER
COLUSA
SACRAMENTO VALLEY
PLACER
EL DORADO
ALPINE
AMADOR
CALAVERAS
TUOLUMNE
MONO
MARIPOSA
MADERA
MERCED
STANISLAUS
SAN JOAQUIN
SACRAMENTO
YOLO
SOLANO
NAPA
LAKE
MENDOCINO
SONOMA
MARIN
CONTRA COSTA
ALAMEDA
SANTA CLARA
SAN MATEO
SANTA CRUZ
SAN BENITO
MONTEREY
FRESNO
KINGS
TULARE
INYO
KERN
TEHACHAPI PASS
SAN LUIS OBISPO
SANTA BARBARA
VENTURA
LOS ANGELES
SAN BERNARDINO
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL
SIERRA NEVADA MOUNTAINS
COAST RANGE
MOUNTAINS

TABLE 2. AGRICULTURAL AREAS AND NET DUTY OF WATER

in sixteen sections of California, shown on Plate III

Section number.	Description of section.	Agricultural area.	Net duty of water.
		Acres.	Feet depth on land.
1	Los Angeles area, Ventura to Redlands	1,310,000	1.75
2	San Diego area. Mexican boundary to San Jacinto and Yucaipa	84,000	1.25
3	Imperial, Coachella and Palo Verde valleys	1,299,000	3.00
4	Antelope Valley and Mojave River areas	1,107,000	2.00
5	Inyo-Kern, Owens and Mono valleys	657,000	2.50
6	Sierra foothills and rolling plains east and south of San Joaquin Valley floor	1,800,000	1.75
7	San Joaquin Valley floor	5,468,000	2.00
8	Western slope of southern San Joaquin Valley	971,000	1.75
9	Santa Barbara, Santa Maria and San Luis Obispo areas	410,000	1.50
10	Salinas and contiguous valleys	296,000	1.75
11	Santa Clara and adjacent valley areas	530,000	1.50
12	Delta lands of San Joaquin and Sacramento valleys	453,000	1.50
13	Sacramento Valley floor	2,694,000	2.25
14	Sierra foothills, and rolling plains east and west of Sacramento Valley floor	2,305,000	1.50
15	North coast area	624,000	1.25
16	Northeastern mountain-valley and plateau areas	1,598,000	1.75
	Total	22,506,000	....

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	Total	22,506,000	....

were all accumulated and confined above that acre. Conventional use, however, has resulted in dropping the unit of area, the acre; and of time, the year; and although not expressed, these are now implicitly contained in the phrase "Duty of Water."

Qualifying terms are in common use, such as "Net" and "Gross." "Net Duty" is the quantity of water measured at the point nearest to its entry and spreading out upon the cropped land. It thus contains the water required for plant growth, together with the spreading or application losses and the losses contingent to storage in the soils prior to absorption by the roots of plants. The "Gross Duty" is this same quantity of water in lake or flowing stream, reservoir or place of storage, together with the conveyance losses and waste over spillways incident to its flow through canals or conduits from the first point of diversion at its natural source, to its point of entry on to the cropped soil. "Net Duty" of water is best adapted to considerations of the requirements of accessory water supplies and in comparing the needs of different localities. "Gross Duty" is a subject for consideration in canal and conduit design and in initial diversion quantities.

The application of waters to large areas in the quantities tabulated at "Net Duty of Water" in Table 2, provide adequate moisture for their intensive cultivation; but in estimating the total water requirements in any locality, portions of the entire area will not need water. Contingent to an intensively developing agricultural community, the rural and urban dwellings, routes of communication and transportation, industries, and improvements, occupy an increasingly large portion of the total area. As the small farm holdings become greater in number, the land is more vigorously cultivated and the production per acre is enhanced; the farm buildings needed for this great activity occupy a larger proportion of the cultivatable area. The total value of improvements, the wealth created and the income derived from agriculture vastly increases, but the farmed area would tend to diminish except for the cultivation of new areas previously unprofitable to farm. The inclusion of new areas among the tilled lands, however, is limited, for after the entire area is brought into use, no additions can be made without destroying improvements which themselves are essential for the tilling of the soil, and also, there are always some lands naturally unfit for cultivation, such as rocky and alkali spots, high knolls and stream beds. These will never be irrigated. Further, in each season a portion of the total area will remain fallow, other portions will be planted but not watered and irrigation water will not be required for either. So, in closely settled irrigated communities, the sum total of the unirrigated lands may be a considerable part of the total area. The studies made in these investigations, indicate that the part of the gross area ultimately requiring agricultural water, is from sixty to ninety per cent in the various sections of the state.

Of all the waters in use for the various purposes of civilization, that employed in agriculture is predominant. In the year 1920, with three and one-half millions of people in California and one-quarter of its arable lands under irrigation, about one-fourth of all waters that can ultimately be made available through storage within the borders of the state, were in use for domestic and industrial supply, irrigation, power generation and mining. The domestic and industrial use was about four per cent of the total, while much of the waters used for generating electric power and in mining, being on elevated lands, was employed a second time at lower levels in irrigating the state's dry soils.

CHAPTER VI.

COMPREHENSIVE PLAN FOR ACHIEVING THE MAXIMUM SERVICE FROM THE WATERS OF THE STATE.

Plans for converting the waters of California to their greatest service in this generation and for all posterity, must give precedence among the many uses for water, to those purposes which are indispensable to man's continued existence. Water for drinking and household use takes priority over that for growing food-stuffs, while water for growing food-stuffs is primary to that for industrial purposes. Were there abundant water for all needs, cognizance of its relative importance in domestic, agricultural and industrial service, could be disregarded. In California, however, where the waters in the streams are replenished by rains that largely occur in a few months of the year, and seasons of meager or bountiful rainfall succeed each other in all variations of sequence, there would be deficiencies of water for present needs during every season, were it not for impounding works already constructed. Only through the construction of still greater and more elaborate works to equalize the erratic stream flow and to transport waters to localities of urgent need, can California continue to enhance its wealth and increase the numbers of its people at the prevailing rate which for the past decade has exceeded that of all other states of the Union but two.[1] The combined increase of population in these two states, however, was only one-third that in California.

A comprehensive plan must primarily insure a full supply of water for drinking and household purposes. But since the present needs for domestic and industrial water supplies are only a twenty-fifth the amount required for irrigation of the agricultural lands now using water, the principle constructive features of a plan for obtaining maximum use of the state's waters, must revolve about its distribution for the greatly preponderant use in agriculture. Further, the magnified urban communities of the future must largely encroach upon lands now classed as agricultural, for these farm areas comprise all the lands that are suitable for residence, except those about the state's seaports. Because of their harbors, commerce and strategic locations, the seaports will expand over adjacent lands now excluded from the agricultural areas on account of being scatteringly settled fringes to population centers or on account of being too rough of surface or steep of slope. But metropolitan areas in all other parts of the state will undoubtedly arise upon the flatter lands classed in this report as agricultural. As these are relinquished for city development, the total consumption of water in any district for both domestic and irrigation supplies will not increase very much, since cities of fairly mature growth use water about

[1] U. S. Census—1920. Population of Arizona increased 63.5 per cent, Montana 46 per cent, while California increased its numbers 44 per cent during the preceding decade.

equal to that required for irrigating crops on the same area. Consequently any comprehensive plan for supplying water to all parts of the state in amounts suited to its future needs for urban and agricultural development, will have accomplished both purposes when all the present lands, classed as agricultural, are provided with an adequate allotment of water to irrigate their surface, and additional allowances are made for the dense urban development that will occur about the state's seaports.

Of other uses for water, though subservient to the primary demands of the household and for growing food-stuffs, that of generating hydro-electric power to light and heat the homes in rural and urban communities, to operate factories, railroads and car lines, to illuminate the streets of cities and towns, as well as to pump and deliver water for the domestic and agricultural use, undoubtedly ranks close to the employment for agricultural purposes. It is through these agencies that accessories to raising food-stuffs are supplied, that farm produces are prepared for consumption, and the necessities and conveniences of civilization are conveyed to all alike, so that a comprehensive plan to obtain the maximum use of the state's waters must dispose of these waters in such a way that a full measure of hydro-electric energy may also be generated.

The agricultural lands of the state, situated on the lower levels, are favorably located to receive the flowing waters of the streams after they have exhausted their inherent energy in tumbling down the steep mountain slopes. Three-fifths of the agricultural area of the state is less than five hundred feet in elevation, and seven-eighths of it is less than twenty-five hundred feet in elevation, while the mountainous water-producing region ascends to heights as great as ten thousand feet above the twenty-five hundred foot level. This spacious region, a steep and rugged country that spreads over half the state, yields practically all of California's waters. These drain into the stream channels and flow past the bulk of the lower-situated agricultural lands in their descent toward the ocean. Thus, the region that abounds in the sheer declivities and swift flowing streams, most essential for the generation of hydro-electric energy, lies above seven-eighths of California's agricultural lands and above those areas that will be mostly occupied by urban development. If the diversions of domestic and agricultural waters from the streams are generally confined to points below the twenty-five hundred foot contour, the areas most favorable for power development one-half the total surface of the state, with its waters nearly all of the state's supply, remain intact for the unimpaired generation of electric energy and these waters may then be re-used on the lower levels for domestic, agricultural and industrial purposes. Therefore a comprehensive plan to serve the maximum area of agricultural land with irrigation water, that makes its diversions of water below the twenty-five hundred foot elevation and that provides additional waters for the growing urban communities about the seaports that are not spreading over agricultural lands, is the constructive measure that will enable the greatest use to be made of California's water resources, and such a plan would give the greatest service to the primary needs of man and provide domestic and irrigation waters in their largest amounts, without

particularly abridging the use of waters for the industries and the generation of electric power.

While the entire amount of California's waters for an average year would submerge the twenty-three million acres of tillable land in this state to a depth of three and a quarter feet if evenly spread over and confined above them and the necessary application to the soil is but two feet in depth annually as a statewide average, still the disparity in location of these agricultural lands with respect to the sources of abundant water supply, presents insurmountable obstacles to the utilization of a considerable part of these waters on the lands that need them most urgently.

In northwestern California lies the area most productive in water of all regions in the state, the North Pacific Coast region. From the evergreen slopes of its timbered mountains, more than one-third of all the state's waters drain off into the ocean, passing on their course, only two per cent of the agricultural lands of the state. This immense volume of water, enough to cover the arable lands of the entire state to an average depth of one foot every year, joins the ocean deep without opportunity of infusing harvest-maturing moisture into those portions of California's soils that are too dry for maximum production without accessory supplies. The oceanward slopes of the Coast Range are separated by more than one hundred miles from the nearest large body of farming land that is deficient in local waters. In attaining heights in an unbroken barrier of from four to nine thousand feet, the Coast Range Mountains effectively block the transportation of the waters from their western slopes to the extensive area of agricultural lands lying to the east and south. Only in projects of great magnitude can portions of these waters be captured and delivered for use on the lands that need them.

Diagonally across the state from this great waterproducing basin of the North Pacific Coast, lies a region in the southeastern corner of California, one-fifth the entire area of the state, mountainous for a large part, but containing at least four million acres of flat lands of which the geography is only partly recorded because of the extreme aridity and uninviting aspect of its parched expanse. Some of the flat lands that skirt the edges of this moistureless solitude, have been fortunate in securing waters for their dry soils. These have responded to irrigation, and their great fertility has brought forth bountiful harvests to repay the pioneer. There were 546,000 acres of this region so irrigated in 1920. However, an area of 2,400,000 acres of the flat lands have been listed as agricultural, for water may ultimately be obtained for considerable areas in this region. Thus in one corner of California, one-third of its water resources are dissipated into the ocean with but small possibility of use, while in the opposite corner of the state, over six hundred miles distant, considerable areas of potentially fertile soils await the import of plant-nurturing waters to awaken their powers of production.

Intermediate in geographic position between these extreme regions, lies the Great Central Valley containing three-fifths of all the agricultural lands of the state. The northerly part of this area, the Sacramento Valley, contains five and one-half million acres of agricultural lands and enough water courses through the streams traversing it, to

submerge these lands on an average four and one-half feet in annual depth; while its southerly part, the San Joaquin Valley, contains eight and one-quarter million acres of arable land, but only enough water flows in its stream to cover them a foot and a third in average depth if spread evenly over them each year. To the west and south of these lands and disposed along the coast from San Francisco to the Mexican boundary, is the South Pacific Coast region, which contains a tillable area of over three million acres, but its streams on an average, yield only water enough to cover these lands a little more than one foot in depth annually. Other agricultural lands, about a half million acres in the San Francisco Bay Region and four and one-half million acres easterly from the Sierra Nevada and the mountain range extending southerly from Tehachapi Pass, have water in adjacent streams that will cover them annually to less than an average depth of one and a quarter feet, excepting those areas that can receive water from the Colorado River. Areas that are irrigable from the Colorado River may obtain amounts more than double this. *To evolve works by which waters may be transported to overcome this uneven geographic distribution of California's waters, so that, as nearly as possible, all these diversely situated bodies of agricultural lands may be served with their needed waters at the least expense, is the main problem to be solved in unfolding the comprehensive plan.*

However, other most important considerations intervene in preparing plans. In addition to the seventy-three million acre-feet of California's waters being located in geographic positions adverse for use on much of the agricultural lands, these waters course down their stream channels in capriciously erratic rates of flow and three-fourths of them reach the lower levels at a season of the year during which they are of little use for irrigation, because the same storms that precipitate the run-off on the mountain collecting areas, usually wet the lower agricultural lands as well. Thus works must be provided to detain large volumes of flood waters on their catchment areas and hold them in reserve for supplementing the diminishing summer flow of the streams at the time needed for irrigation. In holding waters in storage for later use, evaporation is continually active on their surfaces and the stored volumes are constantly depleted through loss to the atmosphere. It is revealed by these investigations that, even with unlimited storage capacity available on every stream, not more than eighty per cent of the state's waters can be brought into use as uniform flow; that, with maximum equalization of stream flow, one-fifth of all the waters would be lost by evaporation while being detained in reservoirs until the time arrives for their use. Thus the four great basins deficient in waters for their agricultural lands, the San Joaquin Valley, the South Pacific Coast Basin, and the regions of San Francisco Bay and of the Great Basin drainage, within whose confines lie two-thirds of all the agricultural lands of the state, would have their already inadequate waters, if developed in their entirety, reduced one-fifth in volume by losses of evaporation.

To further complicate the problem, the waters of some streams, in their flow being less erratic, can be more easily equalized to uniform discharge than in others. To minimize the cost of the works, those streams must be most heavily drawn upon for water that require the least storage capacity to equalize their flow and upon whose drainage

areas cheap reservoir sites may be found. The capacities of storage required to yield the maximum amount of uniform flow for irrigation use varies widely on the different streams. On the streams of least requirements, the maximum development may be obtained with a storage capacity whose volume is less than the annual yield of uniform flow, while on the streams of greatest requirements, a storage capacity fifteen times as large as the annual equalized flow is necessary to obtain the maximum yield. In general, the greatest storage requirements are on streams in the regions of least water production, so that the most effective use of the state's waters may be accomplished only through a superlatively scientific plan.

That the highest attainments of science could be introduced in the preparation of a comprehensive plan, the investigations have assembled masses of data and completed intricate analyses concerning the location, the quantities and the variability of occurrence of the waters of the state. This digest of information has been all-inclusive, and is presented in full in Appendix "A" to this report. It is summarized in Table 1, "Water Resources of California." This audit of California's waters results in the first complete inventory of the waters of an entire state that has ever been assembled.

In addition, data on twelve hundred and seventy reservoir sites have been examined and preliminary estimates of the reservoir capacity and of the water yield were made on nearly eight hundred of these. The field parties of the department made reconnoissance surveys of one hundred and seventy-six reservoir sites and searched three thousand five hundred miles of stream bed for other possible locations. Further, that the amounts of water needed for irrigated agriculture might be ascertained, data were gathered on the quantities of water used on over two million acres of irrigated lands in the state, or more than half the total area irrigated in 1920. These records of water use extend over an average of four years. They are presented in Appendix "B" to this report.

An analysis of all this data discloses that four-fifths of all the agricultural lands of the state may be watered. Additional investigation would probably result in finding means of irrigating still larger areas, but the water would be very costly. The 18,000,000 acres which it is found possible to water is an expanse greater than the entire area in all the western states irrigated in 1919, and three times as large as the area under water in California in the same year.

To accomplish the irrigation of this large area will require the construction of reservoirs having an aggregate capacity of 50,000,000 acre feet, and many miles of large canals to transport water from its source to the regions of need for it. Because of the inclusion of the maximum area in the estimates of cost, the average price per acre for accomplishing the irrigation of the 18,000,000 acres is greater than most projects that are now under construction, but additional areas to those watered at the present time can only be irrigated at greater costs, for they are the residual lands as the more favorable areas for constructive enterprises are selected.

Quoting from the 1919 report to the Smithsonian Institution on irrigation in the western states, "The great bulk of the land west of the hundredth meridian which is not too high, cold, or rocky for agriculture, is arid. Of this arid portion, over 15,000,000 acres have been

placed under irrigation by private or public enterprise, and in carrying out this work, of course, the most favorable opportunities for such irrigation have been developed. It will still be possible to add many million acres to the irrigated area and perhaps to double the area now irrigated, but this must generally be done at a high cost, as the cheap opportunities have been long since exhausted. There are remaining, however, many areas which can be irrigated within feasible costs and will develop values far in excess of the necessary expenditures." These investigations show that it is possible to complete the irrigation of 18,000,000 acres in California alone. This would add 12,000,000 acres to the area under water in the western United States.

In preparing a general plan for this attainment, the complexly involved rights and claims to rights for the use of water in this state were not considered, but rather a plan was devised which comprehends the state as a virgin territory with its waters and soils unsegregated in private ownership. However, inclusion was made of all constructed works, so that the plan does not contain proposals for discarding monuments of attainment of this or preceding generations. The plan would use all existant reservoirs, main canals and distribution ditches. Waters from new sources would be turned into the systems now in use on their arrival in that locality.

In the estimates of cost, entries were included for expenditures made in building all existing works except distribution canals, so that the total cost estimated is for a complete system of storage works and main canals giving uniform service to all lands irrespective of their present stage of development. It was found to be impossible in a general layout to separate the service and costs between areas now under water and those yet to be irrigated, because large areas, now classed as irrigated lands, have supplies that are deficient during the latter part of summer and many projects are short of water during the entire season in years of subnormal stream flow. To make this segregation would require a detail design of the plan in each locality, a work of great magnitude for so large an area as 18,000,000 acres. Therefore the cost estimates here given are the average cost per acre to develop a first-class water supply for all irrigable lands, whether they are now watered or not. They include all costs of construction and of rights of way, for storing waters and transporting them into the regions of use, but do not include the cost of constructing distributing canals or of operating the works, or the costs of acquiring water-rights, of litigation over claims to water-rights, or of damage suits. Neither have credit allowances for power that might be developed at or in the vicinity of the many dams for storing water been deducted in the cost estimates.

The average cost of storage works necessary to develop a full supply for the entire 18,000,000 acres, through all seasons without shortage, is twenty-five dollars per acre-foot of water developed, while the cost to the land for adequate amounts would be forty-five dollars per acre. The cost of canals with appurtenant structures to transport this water to the regions of use would average thirty-five dollars per acre. The total average cost per acre to deliver a first-class supply to the region of use is, therefore, eighty dollars. These costs vary greatly in the different localities.

To effect the watering of so large an area at these costs, it is necessary over the bulk of California's lands to adopt a coordinated scheme of development and distribution of water, that comprise very large areas in interrelated works. To store the waters at the cheapest locations of abundant supply and transport them long distances to the localities of use requires inter-service works of great dimensions. Areas greater than are now under irrigation may be watered without coordinated development and distribution, but a limit is being approached whereby united endeavors almost statewide in extent will be necessary to secure greater service from the state's waters at reasonable costs.

The plan herein set forth requires complete coordination of the distribution of water over large areas, as well as in the construction of the works. This is necessary in order to utilize the inexpensive storage sites to the greatest advantage. Dam sites of low cost often have limited catchment areas draining into their reservoirs that do not yield enough water to warrant the construction of high dams when the draft on them is uniform. But under the coordinated scheme of operation of the comprehensive plan, these dams may be erected to their full height and the cheap storage capacity thus created, utilized to the same advantages as the capacities behind other more expensive dams.

To secure this advantage requires that the draft on all reservoirs be pooled so that in apportioning the total draft between the reservoirs in each season, the largest amounts may be taken from the reservoirs that are filling the quickest. In this way, the draft may be apportioned to small reservoirs situated on large drainage areas so as to empty them more than once a season and thus use excess water that otherwise would flow over their spillways; similarly, reservoirs with watersheds of small yield may be left to fill with accumulating waters during the seasons of plenteous run-off and may be drawn on only during the drier seasons.

In so apportioning the draft, exactly the same results are attained in irrigating the land as by the customs in present use whereby the waters from each reservoir become attached to a particular tract of land and the reservoir is drawn on regularly each year at its maximum rate of yield. Under this prevailing system of individual reservoir-draft it would be useless to build dams to greater heights than is required to equalize the flow of their tributary drainage area for a uniform draft, because no greater yield would be obtained with the higher dams. But when their waters are utilized for over year storage only, for holding over the surplus of wet seasons to dispense it for use in the dry ones that may come several years later, these cheap reservoirs answer just as well as the more expensive ones with larger drainage areas. In either case the same amount of water must be held in storage somewhere for the same length of time, but a great advantage in cost is gained over the customary system of individual reservoir-draft, by the selection of the cheapest sites for storing this water under the system of pooled draft. The scheme of pooled draft of the comprehensive plan, allots the total draft to the various reservoirs so that the greatest efficiency is attained in operating the works. To obtain equal yield to that of the customary system of individual draft on reservoirs, the coördinated scheme of pooling the draft contained in the comprehensive plan, would result in an average construction cost of storage works only slightly more than half that of the individual reservoir-draft system.

The preliminary comprehensive plan outlined in this report will accomplish the irrigation of the maximum area of the state's agricultural lands at the least cost, as well as provide waters for the primary use of domestic supply and leave the great mountainous area above the twenty-five hundred foot contour free for the generation of hydro-electric energy, except for the irrigation of the beautiful mountain valleys, that dot these regions and the table lands in northeastern California. Their total area, however, is only one-eighth of all the tillable soil. On the other hand, much power can be generated below the twenty-five hundred foot level and above the irrigation diversions, especially at the high dams of many of the storage reservoirs. This plan, then, outlines a scheme that will obtain the maximum service from the waters of the state and provide for all users in order of their importance to man's continued existence.

In this plan the source of supply has been selected as close to the needy land as possible, the least expensive storage sites have been selected, and the canals have been routed over the least obstructed paths and a scheme of coordinated use of reservoirs has been included that makes it possible to attain the most efficient service in their operation. The main features of the plan are delineated on the map of California Plate IV, "Preliminary Comprehensive Plan for Maximum Development of California's Water Resources."

Because of the physical limits which the mountain ranges and great distances in California place on the transportation of water, bounds are placed on the areas that naturally group together to their mutual advantage quite like the bounds of the great drainage basins of the state. The plan will therefore be described by major drainage groups.

SAN FRANCISCO BAY DRAINAGE.

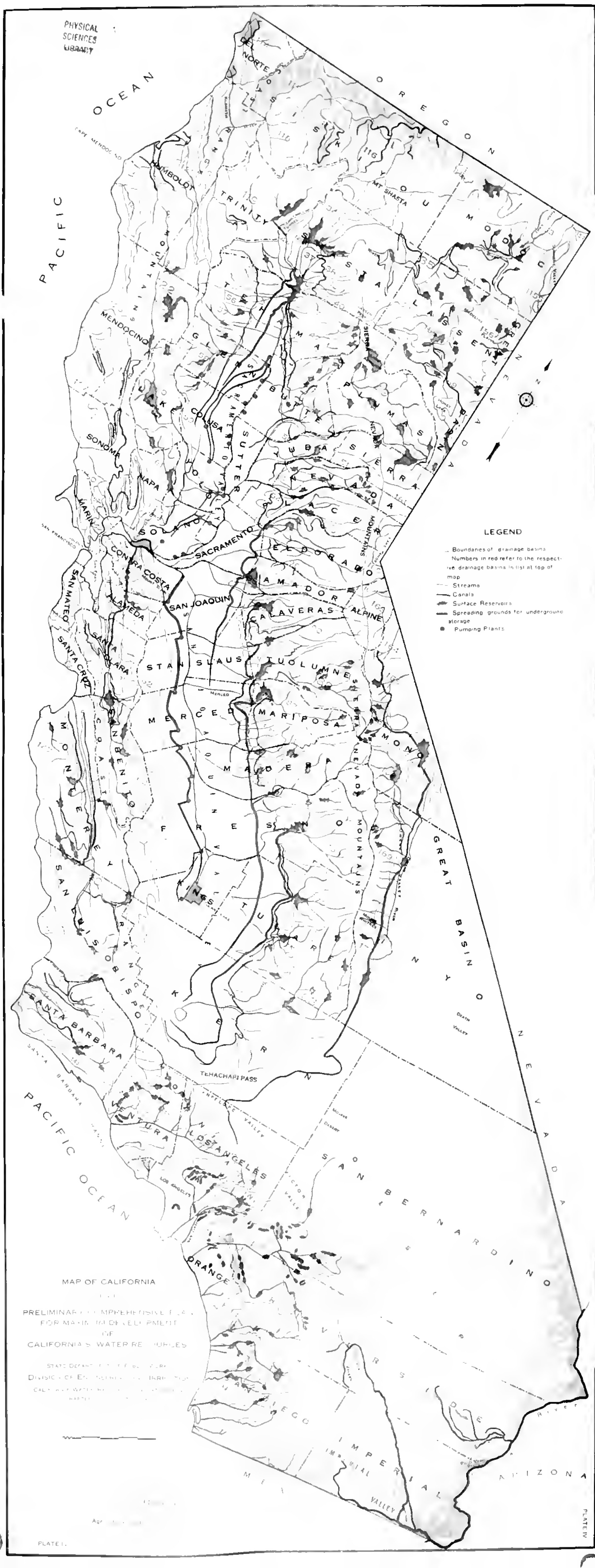
Half the waters of the state in their natural course drain into San Francisco Bay. From the Pit River, which rises in the extreme northeast corner of the state, to the Kern, three-fourths the length of the state towards its southern extremity, these waters gather into the Sacramento and San Joaquin rivers to join with smaller streams that empty directly into San Francisco Bay, in issuing through the Golden Gate into the Pacific Ocean. Within these drainage basins are 14,800,000 acres of lands suitable for agriculture. The comprehensive plan provides for irrigating all but two and one-half per cent of this entire area. Only 4,260,000 acres are now irrigated in these regions.

Ninety-five per cent of the 14,800,000 arable acres in these basins lies in one large continuous body of land on the floor and skirting the edges of the Great Central Valley. Sloping from elevations of five hundred feet above sea-level at the extreme northerly and southerly ends, these lands are barely higher than the sea in the central parts. With an extreme length of five hundred miles, the economic conveyance of the surplus waters of the north half of this valley to the southerly areas that are lacking in water, demands that the plan be adapted to the natural topographic and hydrographic features of the area.

Since seven-eighths of all the waters of these regions drain off the Sierra Nevada Mountains, there is ample for spreading on the easterly side of the valley. In the Sacramento Valley, the east side lands would be served almost entirely by gravity diversions from adjacent streams

DRAINAGE BASINS Listed in numerical order.

34 Sacramento River, Upper
35 Pit River
36 McCloud
37 Churn Creek Group
38 Cow Creek
39 Bear Creek
40 Battle Creek
41 Inks Creek
42 Paynes Creek
43 Backbone Creek Group
44 Clear Creek
45 Cottonwood Creek
46 Sacramento River
47 Mill Creek Group
48 Butte Creek Group
49 Feather River
50 Honcut Creek Group
51 Yuba River
52 Dry Creek
53 Bear River
54 Coon Creek Group
55 American River
56 Red Bank Creek Group
57 Elder Creek Group
58 Stony Creek
59 Willow Creek Group
60 Cache Creek
61 Putah Creek
62 Orestimba Creek Group
63 Panoche Creek
64 Cantua Creek Group
65 Los Gatos Creek
66 Tejon Creek Group
67 Caliente Creek
68 Kern River
69 Deer Creek Group
70 Deer Creek
71 Tule River
72 Yokohl Creek Group
73 Kaweah River
74 [illegible] Creek Group
75 Kings River
76 Dry Creek
77 San Joaquin River, Upper
78 Cottonwood Creek
79 Fresno River
80 Daulton Creek Group
81 Chowchilla River
82 Dutchman Creek Group
83 Mariposa Creek
84 Owens Creek
85 Bear Creek
86 Burns Creek Group
87 Merced River
88 Tuolumne River
89 Wildcat Creek Group
90 Stanislaus River
91 Littlejohns Creek
92 [illegible] Creek Group
93 Calaveras River
94 Mokelumne River
95 Sutter Creek Group
96 Cosumnes River
97 Petaluma Creek Group
98 Sonoma Creek Tributaries
99 Napa River Tributaries
100 Suisun Creek Group
101 Mt. Diablo Creek Group
102 San Pablo Creek
103 San Leandro Creek
104 Claremont Creek Group
105 San Lorenzo Creek
106 Alameda Creek
107 Mission Creek Group
108 Penitencia Creek
109 Coyote River
110 Guadalupe River
111 Los Gatos Creek Group
112 San Francisquito Creek
113 San Mateo Creek Group
114 Smith River
115 Klamath River
116 Shasta River
117 Scott River
118 Salmon River
119 Trinity River
120 Redwood Creek
121 Mad River
122 Eel River
123 Bear Creek
124 Mattole River
125 Noyo River Group
126 Navarro River
127 Gualala River Group
128 Russian River
129 Lagunitas Creek
130 Salmon Creek Group
131 Bolinas Creek Group
132 San Diego River
133 Santa Ysabel Creek
134 San Luis Rey River
135 Santa Margarita River
136 San Jacinto River Tributaries
137 Santa Ana River Tributaries
138 San Gabriel River Tributaries
139 Los Angeles River Tributaries
140 Malibu River Group
141 Santa Clara River Tributaries
142 Ventura River
143 Jalama Creek Group
144 Santa Ynez River
145 San Antonio Creek
146 Santa Maria River
147 San Luis Obispo Creek Group
148 Salinas River Tributaries
149 Pajaro River Tributaries
150 Soquel Creek Group
151 Pescadero Creek Group
152 Tule Lake Group
153 Goose Lake Group
154 Cowhead Lake Basin
155 Surprise Valley Group
156 Madeline Plains Group
157 Smoke Creek Group
158 Eagle Lake Group
159 Honey Lake Group
160 Lake Tahoe Basin
161 Truckee River
162 West Fork Carson River
163 East Fork Carson River
164 West Walker River
165 East Walker River
166 Mono Lake Group
167 Adobe Meadows Group
168 Owens River (Upper)
169 Bishop Creek Group
170 Owens Lake Group
171 Mojave River
172 Antelope Valley Group
173 Whitewater River



MAP OF CALIFORNIA

PRELIMINARY COMPREHENSIVE PLAN FOR MAXIMUM DEVELOPMENT OF CALIFORNIA'S WATER RESOURCES

PLATE I.

and the main canals would be short, but southerly from the American River, a series of five long canals would be necessary in order to completely irrigate the areas eastward from the valley trough. These canals generally would be on the valley floor and serve to transfer waters southerly as they cross the distributing canals now in use. By this means all of the east side of the San Joaquin Valley may be served by gravity.

The westerly side of the Great Central Valley is deficient in local waters, particularly in the San Joaquin where their average annual amount is only 250,000 acre-feet. Their full amount, however, would be distributed by gravity to the higher lands on the edge of the valley floor. In the Sacramento Valley, three canals, each some sixty miles in length, would divert from the main channel of the Sacramento River and spread water to the south and west, but a very considerable area would be served by pumping diversions with comparatively short main canals leading to adjacent lands. Many of these are already constructed. Some areas to the west of the gravity canals would also be served by pumping from these mains. The pumping lifts would generally be less than fifty feet.

The west side of the San Joaquin Valley would be served by one grand canal two hundred miles long. This would follow the flat lands of smooth surface and have nine pumping plants at intervals along its course to raise the water against the natural grade of the valley floor. The greatest lift of the water flowing in this canal to its extreme southern end, would be 400 feet. There would be 650,000 acres served out of the grand canal by gravity, but the other 1,380,000 acres that could take their supply from this canal, require that the water be lifted by pumping for distribution over the land surface. The total pumping lift would be high for most of these lands. About 600,000 acres only would have a total pumping lift of less than three hundred feet, 1,100,000 acres between three and six hundred feet, and 350,000 acres a lift of more than six hundred feet if they are to be watered.

As great as these pumping lifts would be, this plan of distributing the water is much less costly than one of gravity conveyance. To import water to this area by gravity, would require a canal of large dimensions, tortuously following a grade contour on steep mountain hillsides and winding in and out around every rocky spur and into each receding ravine. The total length attained in its devious route would double or treble the air line distance of five hundred miles between the source of supply in the Sacramento River and the extreme southerly lands to be watered. The cost of constructing crossings for a gravity canal at the innumerable drainage channels that it would intercept, alone would probably exceed the total cost of all the works of the comprehensive plan.

In the comprehensive plan, the excess waters of the Sacramento drainage basin would be collected in the main river channels and, by means of a dam across Carquinez Straits below the mouth of both the Sacramento and San Joaquin rivers, this water would be diverted into the lower San Joaquin River from which the grand canal would take its water. Thus the cost of conduit would be obviated for the full length of the Sacramento Valley. The grand canal would follow the smooth valley floor and its excavation would be the cheapest type of

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earth work. It is so designed that by utilizing the storage capacity of Tulare Lake, the pumping plants along its course may operate eleven months in the year, resulting in a considerable reduction in size of canal and of pumps. The waters pumped during the winter months would be stored in Tulare Lake for use the following summer. No flood menace would be involved in filling the Lake during the winter with the comprehensive plan in operation, for the complete development of both the Kings and Kern rivers would absorb in their reservoirs, the flood flows that occasionally fill this lake.

In general, there is opportunity to generate ample electricity for the pumping required in the comprehensive plan, at the dams of storage reservoirs distant less than one hundred miles from the pumping stations. The total cost of these generating works would be very much less than the difference in cost between the canals and pumping plants of the comprehensive plan, and any gravity system that might be devised.

The dam across Carquinez Straits would have many other advantages in addition to diverting the Sacramento waters into the lower San Joaquin River. During seasons of small stream flow, there is a tendency for the salt water of San Francisco Bay to work up into the network of channels that divide the rich delta lands at the mouth of the two rivers, into many islands. The dam below the mouth of these two rivers would prevent any damage to these fertile soils that might result from such occurences. Further, this dam would maintain Suisun Bay in fresh water and make it possible to profitably reclaim all the tidal flats along its margin, and bring unlimited quantities of fresh water to the manufacturing centers arising along the bay shore from Benicia and Port Costa easterly to Antioch. It would provide a low level crossing for railroads and highways whose traffic now crosses Carquinez Straits on ferries. By constructing locks of adequate dimensions, this barrier would offer no obstruction to navigation. It can be designed to afford ample water way for floods of the Sacramento and San Joaquin rivers so that flood heights on the lower river will not be increased over those of the past.

The practicability of locating and constructing such a dam below the mouth of the Sacramento and San Joaquin rivers, has been investigated as far as could be without exploration borings at the various possible sites for its location. It was concluded that a dam in this vicinity is feasible but that extended studies of all possible sites should be pursued before a selection is made.

This dam would be of added value in creating a large fresh water reservoir in Suisun Bay and the delta regions that would have a storage capacity of 500,000 acre feet between the present levels of high and low tide. Supplies of fresh water might be pumped from here for consumption, after filtration, in the metropolitan areas of San Francisco Bay, as well as for agricultural use to supplement the local supplies of the bay region. Thus water might be brought close into the bay region without cost of conduit from the distant sources. These investigations show that waters of the Trinity River and the three forks of the Eel River in the North Pacific Coast region, might be diverted into the Sacramento River drainage through tunnels under the Coast Range Mountains, not prohibitive in expense if their waters

are developed in large quantities. With these diversions effected, there would be plenty of water, in the Great Central Valley drainage area, to supply all its future needs as well as the requirements for all purposes about the San Francisco Bay region.

The diversion for agricultural use from Suisun Bay would be by a canal leading southward through Ygnacio Valley. The water would be elevated in successive lifts into the Livermore Valley. A pumping head of slightly more than four hundred feet would be necessary to lift the water into Livermore Valley and additional pumping would be required to distribute the water over all of its arable lands. A tunnel through the hills separating Livermore Valley from San Francisco Bay would take this water into the Santa Clara Valley at an elevation sufficiently high to permit gravity distribution to practically all lands of this valley not irrigable from the waters of local streams.

The agricultural areas of the bay region to the north, would be irrigated from diversions from the Eel and Russian rivers. Water would be carried in a gravity canal almost one hundred miles in length into the Sonoma and Napa valleys to supplement their local supplies.

Several hundred thousand acres of agricultural lands within the Sacramento drainage area, are isolated from the main body of its lands by the Sierra Nevada Mountains. The Pit River, in the northeastern corner of the state, drains part of a great plateau region to the east of the Sierra Nevadas on the edge of the Great Basin of North America, and cuts through these mountains for a distance of sixty miles in a deep rock gorge to join the waters of the Sacramento River before they emerge into the Great Central Valley. The agricultural areas of the Pit River lie in several parcels along its upper reaches and vary in elevation from 3000 to 5000 feet above sea-level. The comprehensive plan provides for irrigating 263,300 acres of these areas by gravity diversions from the Pit River or its tributaries. Seventeen reservoirs of varying capacity will be required to equalize the stream flow for these diversions.

PACIFIC COAST DRAINAGE BASINS—SAN FRANCISCO TO SANTA BARBARA CHANNEL.

Comprised within five larger valleys and several smaller ones, 890,000 acres of tillable lands lie along the Pacific Coast between San Francisco Bay and Santa Barbara Channel. Of these 135,000 acres are under irrigation at the present time. The water supply in the streams traversing these valleys is enough to cover their agricultural lands to a depth of two feet in an average year, but the flow is so flashy that with unlimited storage, only two-thirds of their waters could be suitably equalized for irrigation use. Nevertheless, three-fifths of the total area can be irrigated under the comprehensive plan. In this plan the waters would be diverted from the streams in each valley and carried to the lands in gravity canals. The costly tunnels through the mountainous regions separating these valleys largely prohibit the importation of any small surplus waters that may occur in adjacent regions, so that the agricultural lands of each valley would be largely irrigated by independent systems.

PACIFIC COAST DRAINAGE BASINS—SANTA BARBARA CHANNEL TO MEXICAN BORDER.

Southward from Santa Barbara Channel skirting the coast and on the Pacific slope of the Southern California mountains, lie 2,300,000 acres of fertile soils. These lie in the valleys of streams draining into the Pacific Ocean that are less separated by mountains than the valleys northward from the Santa Barbara Channel and form an almost continuous body of agricultural land. Although several large streams traverse portions of this area, the total waters are hardly sufficient to cover the arable lands to half a foot in depth in the average year. Their flow is erratic and would require much storage capacity for their complete development for irrigation use. Reservoir sites are few in number and dams expensive. However, it is found that the water supply can be perfected on a large part of the 759,000 acres now irrigated and perhaps 250,000 additional acres be brought under water.

Under the comprehensive plan, surface reservoirs would be constructed and largely used for the temporary detention of the waters in the streams that they might be released in a more or less uniform flow for spreading over gravel beds. Excepting in the southern areas of this region, there are coarse alluvial fills that have a large water-holding capacity and easily yield their contained waters to wells sunk into their depths. Waters spread on the gravel beds of these valley fills would be absorbed to join the subterranean waters of these basins. Severed from contact with the atmosphere, these waters would be held in storage in the porous substrata without loss by evaporation and would be available as needed through pumping from wells. By combining surface and underground storage in a coordinated plan, the maximum service will be attained from these waters, even a greater service than could be obtained from storage in surface reservoirs, for with complete development by surface storage, about one-third of all the water would be lost by evaporation. Without some surface storage, however, to partially equalize the flow, large volumes of flood water would rush off into the ocean too quickly for absorption by the gravels in the stream beds or diversion to artificial spreading grounds. The artificial spreading of water is being practiced with success in some of the basins by diverting the clear waters that follow the first turbid flood flows. These spreading operations can be much extended by the use of surface storage works to partially equalize the flood flows and the employment of additional spreading areas.

These investigations have mapped the location of the absorptive basins in this territory and collected much data on the surface and underground waters.(1) Considerable amounts of water spread on the surface of these basins in irrigation, are known to sink to join the ground waters and increase the available supply for other areas. The total quantity of water in this region is so limited, however, that there cannot be any great increase in the areas watered unless means are discovered of maturing crops with smaller applications of water than are now customary. It is possible as water increases in value, that much may be accomplished in reducing losses by evaporation while applying the waters to the soils but at greater expense than is justifiable at the present time.

(1) See Appendix "C" to this report, Bulletin No. 7, State Department of Public Works, for maps of absorptive areas and underground water contours.

GREAT BASIN DRAINAGE—SOUTH OF LAKE TAHOE.

More than 3,000,000 acres of excellent agricultural lands lie in the south half of the state eastward from the Sierra Nevada Mountains and the range extending southerly from Tehachapi Pass. These are situated in several parcels varying in elevation from below sea-level to 5000 feet or more above. The local waters are small in amount, for of all the waters collected by the mountains that separate these areas from the rest of the state, only ten per cent run off their easterly slopes. But a small part of the entire area could be irrigated if it were not for the Colorado River bringing waters from drainage areas outside the state to within reach of 939,000 acres of these lands in the extreme southeastern corner of the state. There are now 500,000 acres irrigated from the natural flow of the Colorado River in this region, but the area can be almost doubled by the construction of storage works for saving over flood waters. These waters would be diverted in the plan, by gravity canals, that serve the greatest possible area.

The local streams in the northerly part of this region are much more productive than in the south. The adjacent agricultural lands are at elevations greater than 5000 feet. The comprehensive plan would carry most of these waters southerly in a canal two hundred and eighty miles long to areas 4000 feet or less in elevation. The waters of local streams are sufficient to irrigate 430,000 acres, and in all, 1,369,000 acres can be irrigated in these regions.

GREAT BASIN DRAINAGE—NORTH OF LAKE TAHOE.

Eastward from the Sierra Nevada Mountains and northward from Lake Tahoe, there are 667,000 acres of tillable lands situated in mountain valleys and on the plateau region of northeastern California that drain easterly toward the Great Basin of North America. These vary from 4000 feet to 5000 feet or more in elevation and occur in parcels of many sizes. There are now 82,500 acres under irrigation in this region and the comprehensive plan would increase this area by 48,000 additional acres. Storage reservoirs would regulate the stream flow, and the diversions would generally be near the lands to be watered. Short gravity canals would lead the water to the regions of use.

NORTH PACIFIC COAST DRAINAGE.

About half of the agricultural areas of the Pacific Coast drainage lie adjacent to Mount Shasta on the northern and western sides. Situated at elevations of from 2500 to 4000 feet, these lands would take their waters from adjacent streams, principally the Klamath or its tributaries, and convey them by gravity to the regions of use. The other arable lands of the Pacific Coast drainage basins lie in lower levels. Mostly less than 500 feet above the sea, these lands lie in the valleys or on the detrital flats along the lower reaches of the streams. Gravity conveyance of the waters requires one canal over seventy miles in length and two more than twenty miles long. In all 699,200 acres can be irrigated under the comprehensive plan. Only 87,300 acres are now served with water out of a total area of 786,000 acres of agricultural lands in this region.

CHAPTER VII.

SETTLEMENT.

The four millions of people within the confines of California in nineteen hundred and twenty-three markedly distinguish this state from the wild and uninhabited mountains, the unsettled valleys and vacant plains of one hundred years ago. Transfigured through years of toil, the state's lands are now of immense wealth and the source of a great income in foodstuffs and minerals, while in the cities and towns are a multitude of industries that enhance the value of the natural products. Each succeeding generation contributes to these accumulated works that transform the fruits of the valley soils and the minerals and waters of the mountains into means of sustaining greater numbers of people in prosperity and contentment. But the value of these resources and the value of these works is contingent upon their service to people. Neither fertile soil, crop-maturing waters or irrigation and hydro-electric structures; nor harbors, railroads, or industrial centers disclose their intrinsic value or seethe with industry without man's vitalizing energy: rather, they are lifeless encumbrances on wide-flung landscapes unless experiencing human exploitation. So, without man to animate and guide them, great works constructed for converting the resources of the state into life-sustaining and comfort-giving commodities, neither increase its wealth nor add to the contentment of its inhabitants.

Projects for transforming the immense potential wealth of the state's waters into food or into light and warmth, must then grow in size and capacity of output in consonance with the augumenting numbers of people waiting to put their product into use, or those industrial structures, inanimate and without volition, will weather in the elements, and, through nonuse, will deteriorate to early decay before opportunity of service arrives. Enterprises that are carriers of water for domestic and industrial purposes or those which are to distribute its tireless energy in electric current to population centers and rural communities, are readily designed in size to accommodate themselves to growing communities, and select without difficulty, small numbers of employees to operate the works under the direction of trained and skilled superintendents.

However, this not so with systems for carrying the waters of the streams to the agricultural lands that these may produce to their full capacity. On these systems, the users of the water are so intimately dependent upon the supply, their successes and failures are so wrapped up in the cost of the waters and excellence of service, that they are as workers in the larger enterprise of developing water for the land in order that it may produce irrigated crops, rather than as consumers of water furnished by the distribution system. The works, the dams, the canals and the distribution ditches are but part of a system for

increasing the productivity of the soil and until this soil produces with greater abundance, the water impounding and distributing works are of no service to the people. For these reasons, private enterprises, distributing water for agricultural use and selling it as a commodity, have been supplanted in irrigation development, by mutual companies. district organizations or by the governing political subdivision.[1] In no other way have the interests of constructors of the works and users of the water become sufficiently coordinated that success could be attained in the enterprise as a whole.

There are now perhaps, a million or more acres[2] in California, fertile enough, and with water at hand, but which are failing to produce adequately to pay for all the costs including improvements on the land. Much of this is in large holdings and in new districts that have recently been brought under irrigation and, although it will undoubtedly be closely settled and produce to capacity within a few years, at present these lands are lacking in numbers of tillers of the soil to respond to the propitious agricultural environment of this state. At the same time, while these vast areas are but partially productive, eager workers and potential farm owners, anxious to prove their worth, but without money to make a start; skilled university-trained agriculturalists, capable of directing agricultural effort and anxious to exercise their training and accumulated knowledge, are about us in numbers ample to people and intensively farm these million or more acres and many more besides, if provision were made for their occupying the land.

It is generally estimated that a settler, in addition to being an experienced farmer, should have at least from two to five thousand dollars capital to make the start under existing conditions with reasonable expectancy of ultimate success; the success so necessary for maintaining the credit of irrigation enterprises. This ready money is required to level the land, to build a house, a barn, fences; to purchase a plow and harrow, a mower, rake and seed; to procure a horse, and cow, as well as to plant the first crop and sustain the settler until the first harvest is sold. Two thousand to five thousand dollars, often the savings of a life-time, is not possessed by a large number of people experienced in farming, and who are desirous of undertaking the intensive cultivation of an irrigated farm. These requirements so limit the number of prospective occupants for California's agricultural lands that the rate of settlement [3] on the great irrigation projects already constructed is not as rapid as might be desired. In order to enlarge the number of people who may become settlers by reducing the initial cash outlay required, provisions are being made by some colonization enterprises, through which land may be purchased with small payments that extend over longer periods of time than have heretofore been granted.

Although the million or more acres of land in California now failing to put its water supply to use represents a partially idle value in land and works of perhaps $200,000,000, the future is more concerned with

[1]In 1920, less than 10 per cent of the irrigated area of the whole United States was served by commercial enterprises, U. S. Census Report.

[2]U. S. Census Report states that there were 1,675,426 acres which were not irrigated in 1920 but which the works were capable of irrigating. (Some of this is probably land that never will be irrigated.)

[3]U. S. Census, 1920, reports 533,981 acres of irrigated land available for settlement by owners' statements. The Real Estate Commissioner of California, after a canvass of the state, estimates that there are now 950,000 acres available for settlement of which 80 per cent is under irrigation.

increasing the rate of settlement than the present. The lands that are yet to receive irrigation waters are lands that have been left after the more easily developed projects have been completed, and the cost of water for them will be at an enhanced rate per acre over that which has prevailed in the past. These residual lands are equally fertile, but are usually situated more distant from the source of supply. Some are tracts more uneven of surface and so require eleborate systems of canals to carry the waters to the place of pouring out upon the soil. Others have to acquire water rights before a supply may be obtained, and all of them will have to construct storage works to hold over winter flood-waters for summer use and the run-off of wet seasons for times of drouth. The cost of these projects will be large in comparison with the ones undertaken in the beginning of irrigated agriculture when projects were small and the works simple.

Future enterprises also must organize in increasingly large units, for there will be many more problems presented for solution than heretofore, and these must be surmounted in order to consummate ultimate success. Practically all the summer flow of California's streams is now diverted for irrigation use and the lands which can be watered by constructing short canals have been put under irrigation; but only one-quarter of the state's lands that need accessory moisture for greatest productivity can be watered by projects already constructed. Even now, huge combinations of hundreds of thousands of acres have been found necessary that lands situated remote from stream channels or source of supply may be improved. By building many miles of canals and huge reservoirs to augment the summer flow with saved-over flood waters from winter, these projects are preparing to carry water to the lands that, through intensive farming, they may be made to yield harvests commensurate with the favorable climate and fertile soils of California. The united efforts of whole communities is proving to be necessary to bring water to the needy lands which would otherwise remain dry and unproductive or whose yield would only be realized during seasons of copious rains. So that to bring water to the land, large projects with their immense construction programs are proving necessary even at this time, and their size and complication will grow with the future.

The successful culmination of extensive and costly enterprises not alone necessitates that sound plans be adopted for the construction of the works, not alone that they may be erected in an efficient manner, not alone that they bring water to fertile soil at the time and in the quantity needed, but also that the land be quickly occupied by the large number of tillers of the soil, which irrigated agriculture demands to nurture and harvest the increased yield. The fruition of effort, the repayment of borrowed capital in interest and principal, and the production of wealth to the community involve thousands of operators in these large enterprises, each farming from twenty to forty acres of irrigated lands. The running of the waters through the constructed ditches or even on to the plowed fields does not make the land produce. The yielding of harvests is just as necessary for the successful project as to secure adequate sums of borrowed money with which to build the works. The very essence of utility of these works is the interested and tireless efforts of the farm operators that strive with

and overcome the many annoyances incident to maturing crops on the land.

But are there sufficient numbers of people possessing the experience and skill, the capital and desire, to animate these works and quickly bring the lands to fruitful harvests under the requirements of existent conditions of land sales and farm credits? The holders of large properties for several years past have been searching for them and many still believe that they may be found, but their only partly rewarded efforts are indicative that perhaps they are not to be immediately found in the numbers desired.

As the years succeed themselves, the markets for California's farm products are ever widening. Refrigerator cars, fast express trains, and the cold storage of ocean transport are carrying California's fruits and foods for display in markets undreamed of a few years ago, and the demand for these is increasing at an accelerated rate. With propitious climate and soils, this state is attaining ranking position, a precursor to all the states of the Union in value of agricultural and horticultural products yielded by their lands, and an analysis of the reports of the United States census indicates that there will be a market for California's products in 1940, but seventeen years hence, three-fold greater than in the year 1920. The multiplying population of this state also demands food in greater and even greater amounts, for the state is growing fast. During the decade that closed with 1920, California experienced an enlargement in the numbers of people inhabiting its farms and cities, of forty-four per cent of the aggregate of 1910.

These investigations show that there is land and water ample for production commensurate with this enlarging demand for California's agricultural products, and the past success in financing irrigation construction demonstrates that money will be at hand to erect the works and fashion the canals, but the greatest success can only be attained through effecting a system of colonizing the land that will hasten the influx of settlers and secure a multiplicity of tillers of the soil without delay, so that long periods of stagnation between their construction and time of use may not bring embarrassment to the enterprises. The large units in which future development must be organized will make it increasingly desirable to accelerate the rate of rural settlement of this state.

Two examples of well coordinated and systematized colonization may be seen at Durham in Butte County, and at Delhi in Merced County, the two state land settlement projects.[1] However, these two colonies are but a demonstration of possibilities in stimulating rural settlement for their combined area is only 13,920 acres. A statewide stimulus to the occupancy of farm lands would greatly increase the naturally expeditious growth of California's irrigated communities, insure a full measure of production to meet all demands, and assist California in seizing and holding agricultural and horticultural supremacy among the states of this nation.

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[1]For description of these projects see "Report of Division of Land Settlement," a subdivision of the Department of Public Works of the State of California, the report being Part V of the first biennial report of that department, dated September 1, 1922.

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